GEOARCHAEOLOGY, PALEOENVIRONMENTS, AND HUNTER-GATHERER LAND-USE INTENSIFICATION IN THE CAPROCK CANYONLANDS OF NORTHWEST TEXAS, USA

by

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ABSTRACT

The eastern Escarpment Breaks or "Caprock Canyonlands" are an ecological and physiographic boundary in northwest Texas, USA, between the Southern High Plains to the west and the Central Lowlands to the east. The canyonlands are defined by the steep Ogallala caprock escarpment, remnant mesas, and co-alluvial fans, and have experienced episodes of severe erosion during the late Quaternary. In stark contrast to the flat, featureless Southern High Plains surface, the canyonlands contain abundant springs, lithic resources, shelter, and plant and animal food sources that attracted hunter-gatherer groups. This dissertation examines the relationship between late-Quaternary geomorphic processes, paleoenvironments, and hunter-gatherer land-use intensification in the canyonlands compared to adjacent regions. New pedologic, lithologic, radiocarbon, and multiple-proxy paleoenvironmental data (i.e. stable carbon isotopes, phytoliths, and diatoms) are presented from the soil and sediment archives from landforms of different ages. Results show that the canyonlands offered a landscape with a more diverse plant community and more effective moisture compared to western Texas, Oklahoma, and Kansas. Intensive erosion has mostly removed sedimentary deposits and cultural materials dating to the late Pleistocene and early Holocene, with the exception of co-alluvial fans. However, the eroding slopes near the edge of the caprock escarpment exposed a record of *in situ* Archaic to Protohistoric-aged materials at the surface, specifically fire-cracked rock (FCR) features (n=385). With prehistoric hunter-gatherer land-use intensification and population estimates tied to site discovery and numerical dating, it is critical to measure erosion bias and correct human population estimates based on potential sites lost. Thus, the impacts of intensive erosion on FCR-feature preservation were modeled using the Revised Universal Soil Loss Equation (RUSLE). A method for calculating prehistoric demographic changes is presented, where archaeological preservation bias

is accounted for after determining the density of hearth features from landform surfaces of known ages. When we understand geomorphic processes, paleoenvironments, and the extent to which the archaeological record has been affected by erosion, we can make more substantiated conclusions about the archaeological patterns that inform us about human behavior.

ACKNOWLEDGEMENTS

I would like to thank my committee for their time, commitment, and mentorship: Rolfe Mandel, Fred Sellet, Brent Metz, Dan Hirmas, and Carlos Cordova. I thank Jack Hofman who also served on my committee and provided resources and feedback throughout the dissertation's early stages. Rolfe and Dan each spent one day with me in the field and their perspectives were invaluable. All of you have contributed to my success and have pushed me to become a better writer, teacher, anthropologist, and Earth scientist – thank you!

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Several people assisted me in creating and maintaining the Geoarchaeology and Paleoenvironment Research Laboratory at the Kansas Geological Survey so that I could perform my laboratory analyses for this project. For their efforts, I would like to thank Rolfe Mandel, Mickey Ransom, Jon Smith, Ashley Zung, Bridget Sanderson, Celeste McCoy, Jeff Heinzman, Matt Jacobson, Andrew Gottsfield, Erin Dempsey, Byron Sudbury, Greg Ludvigson, and Dan

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Special thanks to Brian Lagotte, formerly of the KU Graduate Writing Center, who transformed the writing processes for me, Byron Sudbury for his assistance with phytoliths (and many other things), and Barbara Winsborough for her assistance with diatom identification. I would like to recognize Kathleen Nicoll, who helped me organize a geoarchaeology session at the 2011 Geological Society of America conference and co-edited a special geoarchaeology volume with me for *Quaternary International*, published in 2014, which included portions of this dissertation research. Her mentorship and friendship throughout the dissertation process has been invaluable. Finally, to my friends who have been there through it all, especially Ashley Zung, Matt Joeckel, Mark Grimsley, Bridget Sanderson, Laurie Comstock, Patrick Green, Josh Quarles, Kevin Fenyak, and Jason Jantz – thanks for keeping me sane, and for being there when it counts.

This dissertation is dedicated to two scholars who passed away before its completion: Dr. B.L. Allen and Dr. Mark J. Lynott. B.L. shared his contagious, always youthful enthusiasm of soils with me, and encouraged me to pursue soil science. Mark's unconditional support and mentorship since we first met at Hopewell Cultural National Historical Park in 2005 propelled me to where I am today. I miss them both.

Dedicated to:

Dr. B.L. Allen
(1923 - 2012)

and

Mark J. Lynott
(1951 - 2014)

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CHAPTER 1

INTRODUCTION

This dissertation comprises three separate papers presenting the results of geoarchaeological research conducted in northwest Texas. All three papers contribute to the ongoing interdisciplinary Lubbock Lake Landmark regional research program that seeks to understand late-Quaternary cultural adaptations and ecological change on the Southern High Plains. The following chapters are stand-alone articles that have been published in or submitted to a peer-reviewed journal, or are in preparation for submittal to a journal. Chapter 2 presents the soil stratigraphy and history of landscape evolution in the study area, and evaluates the results of investigations within a conceptual geoarchaeological framework. Chapter 3 presents the paleoenvironmental context of the research area, including stable carbon isotope, phytolith, and diatom results from a preserved record of Pleistocene and Holocene soils and sediments. The results are compared to regional paleoenvironmental records from archaeological sites. Chapter 4 moves away from conceptual geoarchaeological models and uses a soil erosion model to quantify archaeological preservation bias in order to ascertain hunter-gatherer land-use intensification and demographics. The results of this dissertation contribute to the larger understanding of the connection between landscape evolution, paleoenvironments, and human behavior inferred from the preserved archaeological record.

Research Overview and Justification

Today, northwest Texas is a dry, flat landscape, homogenized by people after two centuries of cotton agriculture and cattle grazing, but the relationship between humans and the landscape was not always this way. Since ca. 12,000 yr B.P. (uncalibrated), humans have occupied this region known as the Southern High Plains, a broad, flat plateau within the Great Plains (Figure

1). Humans experienced dramatic changes in climate, flora, and fauna on this landscape, and adapted to the changing climate, hunting available game and gathering available stone and plant resources. Changes in stone tool technology and landscape use have been recorded in archaeological sites throughout the Southern High Plains, and represent hunter-gatherer adaptive responses.

Archaeologists do not yet fully understand the "Escarpment Breaks" or "Caprock Canyonlands" and how hunter-gatherers used this area in conjunction with the surrounding High Plains and Osage Plains. The challenges of the eroded, rugged landscape, and the assumption that there are few *in situ* archaeological sites have discouraged extensive archaeological research. However, during recent surface reconnaissance at the escarpment edge near Post, Texas, archaeologists have recorded nearly 400 cultural features, mostly the remnants of cook-stone features such as hearths, spanning the Paleoindian through Protohistoric cultural periods (Hurst et al., 2008, Backhouse and Johnson, 2007a) (see Figure 2 for cultural chronology). The abundance of hearths appears to be unique for this region (Backhouse and Johnson, 2007b). Also, archaeologists have documented sites where Ogallala caliche gravels were quarried; these rocks were used for lining hearths (Backhouse and Johnson, 2007a) and making stone tools (Hurst et al., 2009). Thus, the Caprock Canyonlands hold a rich archaeological record that may offer clues about how Plains people used the dynamic landscape. In particular, the changes in distribution, abundance, size, and type of hearth feature during the Holocene, beginning about 8,000 B.P., may inform us about how people changed or intensified their use of the landscape and its resources in conjunction with the changing landscape.

Since the Caprock Canyonlands differ ecologically from the adjoining physiographic regions, the cultural expression on the landscape also differs, but we do not know to what extent.

Boyd (2004) first recognized the Caprock Canyonlands as its own archaeological region, distinct but related to the adjacent Southern High Plains to the west and Central Lowlands to the east. However, until more is learned about the area, archaeologists rely on established cultural periods for the Southern Plains, which are as follows (in uncalibrated ^{14}C yr B.P.): Paleoindian (11,500-8,500 B.P.), Early Archaic (8,500-6,000 B.P.), Middle Archaic (6,000-4,500 B.P.), Late Archaic (4,500-2,000 B.P.), Ceramic (2,000-500), and Protohistoric (300-500 B.P.) (Johnson and Holliday, 2004). In general, the cultural periods are divided based on broad changes in technology and subsistence strategy associated with changing flora and fauna. Broad cultural periods are further subdivided, often by regional cultural manifestations expressed in technology, i.e. distinctive projectile points. For example, the Southern High Plains Paleoindian cultures are subdivided into Clovis (11,500 to 11,000 B.P.), Folsom (10,800 to 10,300 B.P.), Plainview (ca. 10,000 B.P), and Firstview (ca. 8,600 B.P.) (Johnson and Holliday, 2004). The Clovis mammoth hunters of the terminal Pleistocene manufactured large, fluted spear points, while Folsom bison hunters of the early Holocene manufactured smaller points with larger flutes. Thus, technological changes in the archaeological record are associated with the resources on the landscape in changing environments.

Caprock Canyonlands archaeological research is scant compared to the Southern High Plains (Holliday, 2000) and Central Lowlands (Ferring, 2000) because of the paucity of *in situ* archaeological sites across the rugged landscape. For example, north of the study area near Amarillo, Texas, Tule Canyon was surveyed for archaeological material with little success because "the nature of the topography, the wide variation in microhabitats, the severe wind and water erosion, and the limited access and egress in the Lower Tule all resulted in a widely scattered and, for the most part, low yield in sites" (Katz and Katz, 1976:1). Thus, the lack of knowledge about how geomorphic processes are filtering the archaeological record in this highly erosive landscape, the lack of understanding about how the plant communities differ from adjacent regions, and the rich cultural expression on the surface of the canyonlands landscape makes the study area appropriate for a multi-faceted geoarchaeological study.

The geoarchaeological approach is such that before taking the preserved archaeological record at face value, we first need to evaluate how geomorphic controls and climate drove the landscape patterns of erosion and preservation. In other words, archaeological sites are the connection to human behavior; therefore, we must assess the formation of the archaeological record before we use the record to inform us about human behavior. Furthermore, putting the archaeological record into a bioclimatic context informs us about how humans may have altered their use of the landscape due to climate-driven pressures. Finally, when we can predict the patterns of erosion and quantify archaeological preservation bias, we can more accurately predict archaeological site location and model potential number of sites lost. Knowledge of landscape patterns helps us predict future landscape responses to climate change, but it also helps us assess the temporal and spatial patterns of the archaeological record that inform us about human behavior.

The Geoarchaeological Approach within Anthropology

Because of the broad nature of the holistic study of humans, anthropology, perhaps inadvertently, has fostered the emergence of subdisciplines of the four subfields that invoke diverse methodologies and theoretical frameworks—creating methodological hybridization (Calcagno 2003)—for example, medical anthropology and geoarchaeology. Although phrases such as “archaeology is anthropology or it is nothing” quipped by Willey and Phillips (1958), have served up allegiances to four-field anthropology, the concern at the national level over the fragmentation of anthropology with minimal subfield collaboration (Calcagno, 2003) under the "derelict" four-field approach (Fox, 2003) had been pointed out earlier as a result of the lack of understanding diverse methodologies (Jones, 1991). In fact, Franz Boas (1940:244), who initiated the four-field structure many anthropology departments still adhere to today, realized that with the "bewildering variety of approaches, all dealing with racial and cultural forms, it seems necessary to formulate clearly what the objects are that we try to attain by the study of mankind." Yet Boas recognized that methodologies from prehistoric archaeology, paleontology, and biological and cultural anthropology could be combined to produce the best interpretations of culture.

Since the movement away from culture-history explication toward settlement pattern studies (Willey and Phillips, 1958) and the development of processual archaeology (Binford, 1962), our understanding of the process of culture change rapidly advanced. However, there were limitations to early processualism, with the archaeological record viewed as a fossil record (Binford, 1964) reflective of the *direct* patterns and structure of extinct societies (Thompson and Longacre, 1966). Instead, Ascher (1968) recognized the need to distinguish between the action of natural and human agents, an idea coalesced by Schiffer's (1972, 1987) "formation processes," where natural processes that are part of the archaeological context affect the cultural systemic context. Indeed, unobserved human and natural processes formed the observable archaeological record, which we interpret through theoretical constructs linking material remains to humans (Bamforth, 1999). Over time, the theoretical framework of geoarchaeology was shaped by the recognition that both soils (Wood and Johnson, 1978; Mandel and Bettis, 2001) and landscapes (Waters and Kuehn, 1996) are dynamic open systems that require thorough understanding before interpreting the archaeological record. Needing to understand site formation processes for the best inferences of behavior required a link between archaeology and Earth sciences (Stein, 2001). Today, we understand the natural processes impacting the archaeological record more than ever through the application of many Earth science techniques to archaeological sites and landscapes.

Despite its relatively late coalescence as a thriving subdiscipline, the premise of a geoarchaeological approach—"the application of any Earth-science concept, technique, or knowledge base to study the artifacts and the processes involved in the creation of the archaeological record" (Rapp and Hill, 2006: 1)—is not new. In the 1840's Charles Lyell, father of geology, recognized that stratigraphic evaluation of archaeological sites is central to assessing cultural chronology and for settling debates concerning human antiquity (Rapp and Hill, 2006). The emerging stratigraphic concepts caused a methodological shift for the nature of archaeological excavation by the early 20th century—this change has been cited as the first "new" archaeology (Browman and Givens, 1996). Thus, archaeology was "equally dependent on geology, biology, and geography during its development and is heavily dependent on the natural sciences" (Butzer, 1982) even prior to its place within four-field anthropology.

During the 1920s, in the American southwest and on the Southern High Plains, archaeologists were concerned with stratigraphy and site formation processes of prehistoric sites containing Pleistocene faunal remains (Holliday, 2000). To geoscientists and archaeologists such as E.H. Sellards, C. Vance Haynes, and Claude C. Albritton, "geologic research was inseparable from their approach to archaeology" (Holliday, 2000: 11). They sought to dismiss the dogmatic anthropologists, Ales Hrdlicka and William Henry Holmes, who denounced the discoveries of Native American skeletons in sediments older than four or five thousand years (Adovasio and Page, 2002). By the 1970s, United States federal law mandated cultural research management (CRM), and consulting firms began geoarchaeological investigations to understand site formation processes and discover archaeological material. This was particularly important in the Great Plains of North America that had been considered devoid of people during the middle-Holocene Altithermal (Mandel, 2000). By 1976, Colin Renfrew coined the term "Geoarchaeology" when the subdiscipline coalesced as a hybrid within anthropology, geology, and geography departments (Goldberg and Macphail, 2006). Thus, the subdiscipline has grown since the late 70s, emerging as a nexus science that encompasses virtually all sub-fields of the geosciences, including aspects of stratigraphy, geochemistry, palynology, geomorphology, soil science, climatology, geophysics, and geochronology. As a result of the breadth of interdisciplinary interaction, we are better able to inform our understanding of archaeological site formation processes, human-landscape interactions, behavior, and cultural activities. For example, geoarchaeological research has been central to chipping away at the North American "Clovis-first" paradigm due to stratigraphic and geomorphic evaluations and the advancement and expansion of dating methods and micromorphology (see Lopinot et al., 1999; Ray et al., 2000; Dillehay, 2000; Adovasio and Page, 2002; Waters and Stafford, 2007; Smallwood and Jennings, 2014). Today, as Nicoll and Murphy (2014) pointed out, additional conceptual and technological advances in the geosciences have enhanced archaeology in the areas of site discovery, documentation, and prediction, absolute age-dating, raw material analysis, and taphonomy and site formation.

This dissertation builds on the larger regional geoarchaeological research for the Great Plains. It uses previous conceptual or qualitative geoclimatic and geoarchaeological assessments of the landscape (see Blum, 1989; Blum et al., 1992; Waters and Kuehn, 1996; Mandel, 1995; Beeton and Mandel 2011) for comparison to the Caprock Canyonlands study area. These conceptual models are based on the premise that geologic controls "filter" the archaeological record (Figure 3; Mandel, 2006) creating predictable patterns and ages for buried soils within alluvial fills, whereby the potential for the presence or absence of archaeological deposits of certain ages can be predicted. In more highly erosive areas, the premise is that there is an inverse relationship between the volume of preserved sediment and the recommended intensity of subsurface reconnaissance (Figure 4; Blum, 1989; Blum et al., 1992). Both models explain how periods of erosion can lead to archaeological preservation bias.

Second, this dissertation supplies paleoenvironmental data at multiple scales to demonstrate the diversity of plant communities within the Caprock Canyonlands compared to the Southern High Plains. These data add to regional millennial-scale paleoenvironmental data for the archaeological record and provide additional context for the recorded cultural features within the study area. Furthermore, fine-scale data gleaned from plant microfossils and periods of more effective moisture will aid future climate modeling and links between human-environment interactions at different scales, i.e. human ecology (Butzer, 1982), historical ecology (Thompson, 2013), and niche construction (Laland and O'Brien, 2004).

Finally, the larger significance of the dissertation shows how we can begin to move beyond conceptual geoarchaeological models and move towards quantitative models that can be directly compared to the archaeological record. Geoarchaeological models, such as the one presented in Chapter 4, can be compared to radiocarbon age frequencies from the archaeological record used to infer land-used intensification and prehistoric demographics.

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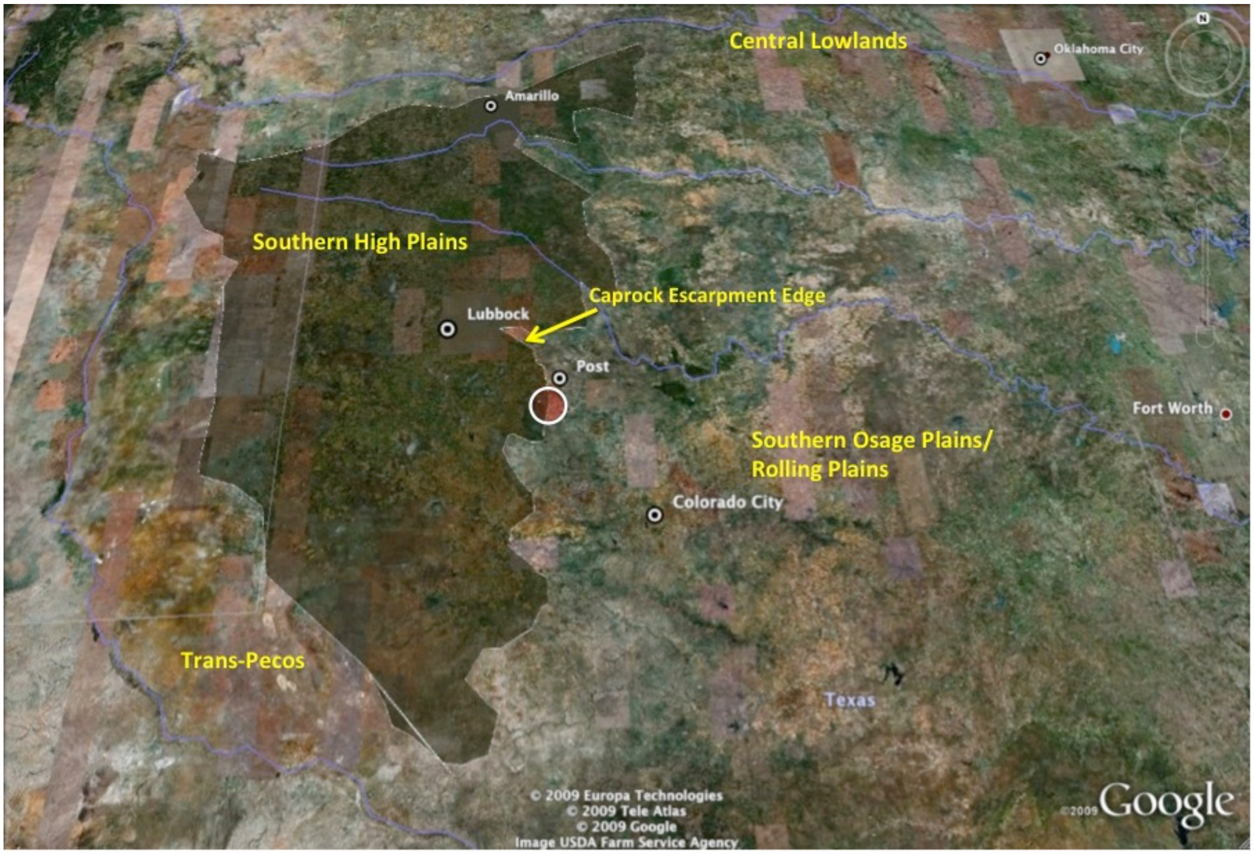

Figure 1. Google Earth image of the regional southern Plains and physiographic provinces. The Southern High Plains is highlighted and an arrow points to the eastern Ogallala caprock escarpment edge that marks the transition into the Caprock Canyonlands. The study area for this dissertation is marked by the circle.

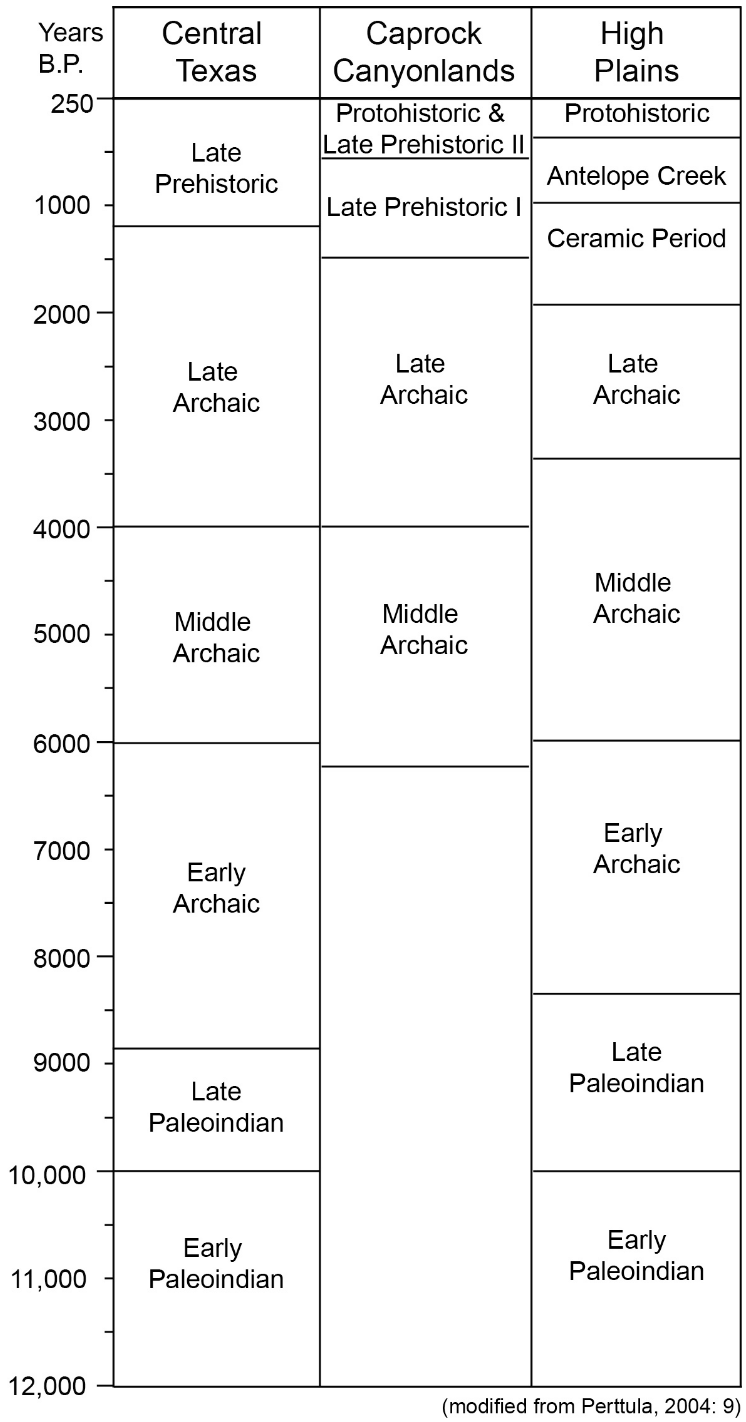

Figure 2. Cultural chronology comparisons for Central Texas, Caprock Canyonlands, and Southern High Plains, based on Perttula (2004) in uncalibrated radiocarbon years B.P.

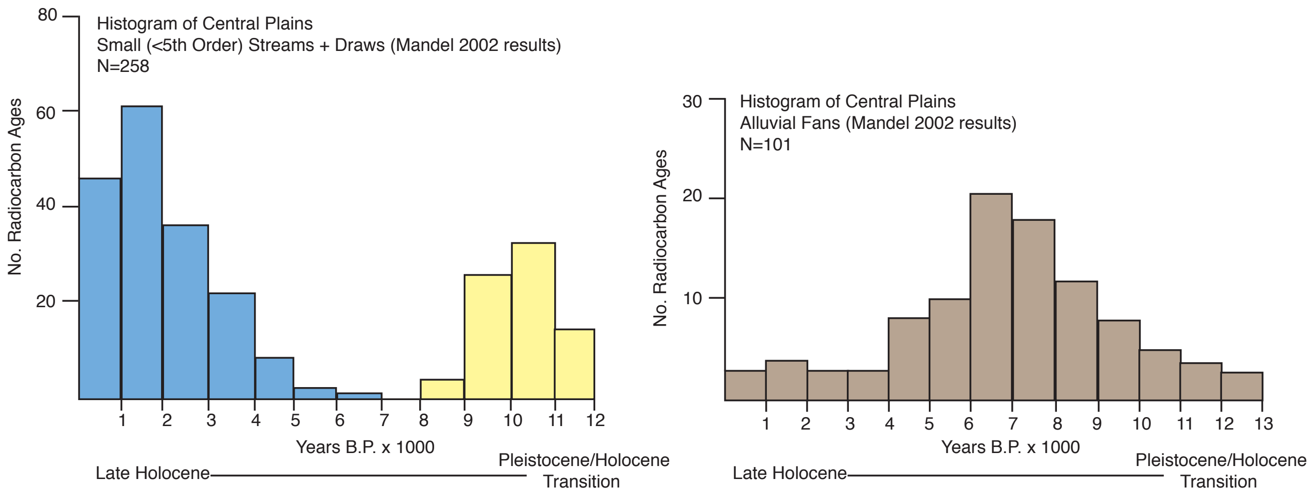

Figure 3. Central Plains geoarchaeological conceptual model based on histograms of radiocarbon age frequencies from small streams (blue), draws (yellow), and alluvial fans (brown). Redrawn from Mandel (2006). Based on these data, archaeologists can determine the potential (i.e. high or low) of locating archaeological deposits of known ages based on stream order and landform.

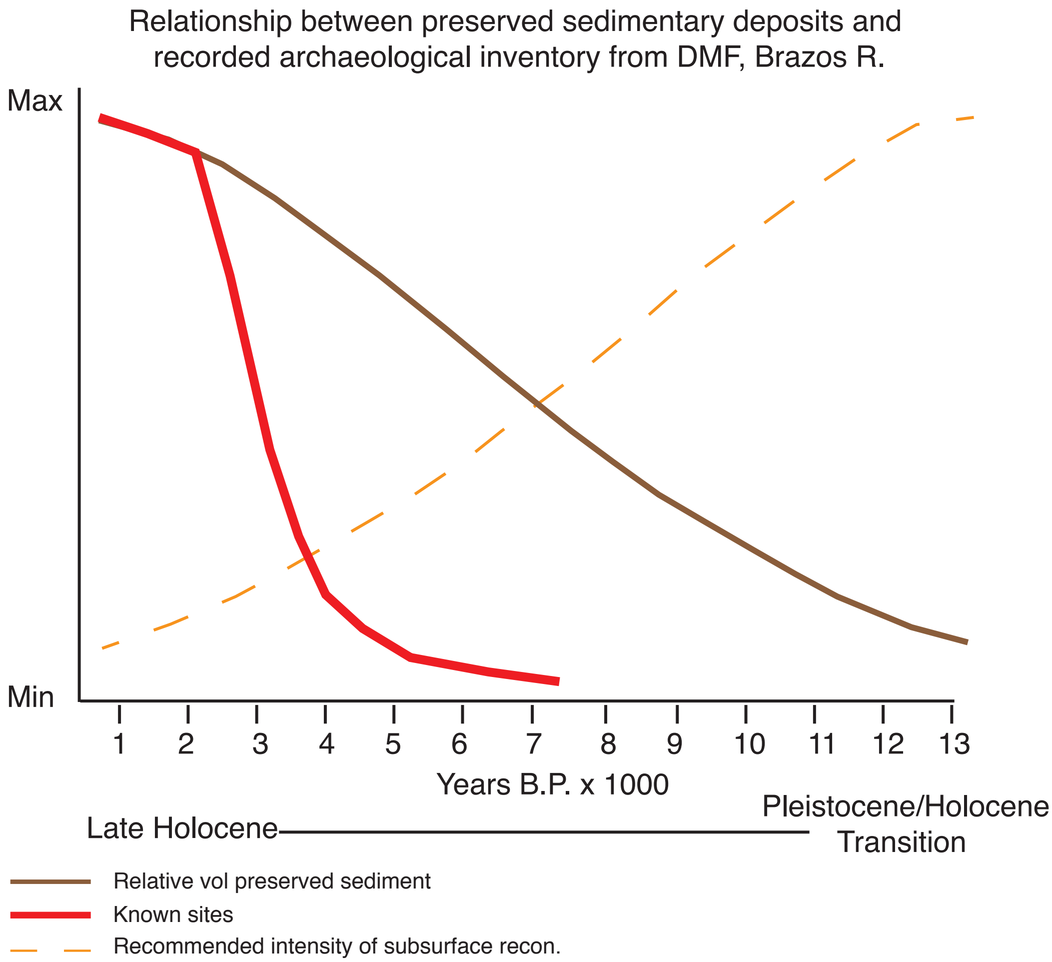

Figure 4. Geoarchaeological conceptual model for the Caprock Canyonlands and Rolling Plains from Blum (1989) and Blum et al. (1992). The model shows an inverse relationship between the volume of preserved sediment and the recommended intensity of subsurface reconnaissance.

CHAPTER 2

Late Quaternary Landscape Evolution, Soil Stratigraphy, and Geoarchaeology of the Caprock Canyonlands, Northwest Texas, USA

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Abstract

In northwest Texas, USA, between the Southern High Plains to the west and the Central Lowlands to the east, lays a geographic boundary known as the "Escarpment Breaks" or "Caprock Canyonlands." The canyonlands contain abundant springs, lithic resources, shelter, and plant and animal food sources that attracted hunter-gatherer groups. A geoarchaeological study was conducted in the canyonlands to determine the effects of late-Quaternary landscape evolution, especially intensive erosion, on the region's archaeological record. Geomorphic and stratigraphic field research and a total of 95 new radiocarbon age determinations, 94 of which were determined on paired samples, aid in reconstructing an understudied dynamic and erosive landscape, and explain how the landscape has changed. The pattern is similar to reported data from the Central Plains and western Rolling Plains but dissimilar to the Southern High Plains. High rates of erosion and geological controls on the South Fork of the Double Mountain Fork of the Brazos River, a 4th order stream, have hindered the discovery of deeply buried soils and *in situ* Paleoindian artifacts and features, but a late-Holocene pedocomplex is relatively intact in valley fills beneath remnants of the T-2 terrace of the South Fork. The eroding slopes near the edge of the caprock escarpment exposed a record of *in situ* Archaic to Protohistoric-aged materials. The eroding slopes should be targeted for future quantification of erosion and archaeological preservation bias for the canyonlands.

1. Introduction

A steep, abrupt, approximately 300 km-long north-south escarpment marks the eastern edge of the westward eroding Southern High Plains in Northwest Texas. This physiographic boundary, referred to locally as either the "Escarpment Breaks" (Texas Parks and Wildlife, 2011) or "Caprock Canyonlands" (Flores, 1990; Boyd, 2004) (hereafter: canyonlands), is defined by rugged incised canyons, remnant mesas, and alluvial outwashes (Figure 1; Gustavson and Simpkins, 1989). The Brazos, Canadian, Red, and White rivers flow west to east through the canyonlands, where the topography transitions to more gentle hills of the Osage Plains section of the Central Lowlands physiographic province (Ferring, 1995; USGS, 2002), referred to locally as the Rolling Plains. Regional topographic diversity occurs along the escarpment, but in general, with the Rolling Plains to the east and High Plains plateau to the west, the canyonlands landscape stands out in sharp contrast to its surroundings.

The canyonlands mark a distinctive geographic boundary between the Southern High Plains to the west and the Rolling Plains to the east, making it an ideal area to assess archaeological and geoarchaeological questions in relation to the adjacent physiographic regions by examining late-Quaternary landforms and soils. Ongoing interdisciplinary research near Post, Texas (see Backhouse and Johnson, 2007a), is providing new information about hunter-gatherer landscape interactions, including hearthstone and lithic procurement strategies in the region (see: Backhouse and Johnson, 2007b; Backhouse et al., 2009, 2010; Hurst et al., 2010). Here, as part of the interdisciplinary effort, we evaluate the landscape evolution of a portion of the canyonlands along the South Fork of the Double Mountain Fork of the Brazos River (hereafter: South Fork) within the broader regional context of the Southern Plains. We compare soil-stratigraphic records from the Great Plains (e.g., Blum et al., 1992; Thurmond and Wyckoff, 2004; Bettis and Mandel, 2002; Mandel, 1992, 2006, 2008; Quigg et al., 2010; Beeton and

Mandel, 2011) with the record from the canyonlands to create a more robust understanding of the landscape and to provide context for archaeological materials, and assess the potential for future archaeological site discovery.

We framed our study around generalized conceptual models for landscape evolution, landform stability, and geomorphic bias in the archaeological record. First, we consider a general late-Quaternary "geoclimatic" conceptual model, which emphasizes that climate processes drive geomorphology to a large extent. In other words, destabilization and stabilization of the landscape are tied to climate patterns, where precipitation influences vegetation cover, erosion, and fluvial aggradation and degradation (Hall, 1990; Bull, 1991). For example, arid climate in the Great Plains during the mid-Holocene caused loss of vegetation, which led to landscape destabilization, an increase in erosion, alluviation on the Central and Northern Plains (Antevs, 1952; Clayton et al. 1976; Mandel, 1995; Artz 2000), and eolian sedimentation on the Southern Plains (Holliday, 1989b, 1995, 2000, 2001). Region-wide examination and radiocarbon dating of sediments and soils preserved in alluvial landforms (e.g. terraces and fans) of the Central Plains have revealed coeval patterns of erosion and deposition based on stream order and landscape position (see: Mandel, 1992, 2006, 2008; Bettis and Mandel, 2002; Beeton and Mandel, 2011). Although a late-Quaternary geoclimatic model is well established for the Great Plains, less is known about the specific geoclimatic patterns within the highly erosive canyonlands.

Second, we evaluate the relationship between geomorphology and the archaeological record with a conceptual geoarchaeological landscape model for the western Rolling Plains of Texas. The model is based on a geomorphic and archaeological survey for the Justiceburg Reservoir (now known as Lake Alan Henry; Blum, 1989; Blum et al., 1992) and known periods of soil development/stability and “catastrophic stripping” from the reservoir area (Boyd, 1997). Based on geomorphic patterns, the model presupposes that a strong (positive) relationship exists between the relative volume of preserved sediment and the recorded archaeological inventory. Thus, “in order to achieve a more representative archeological record, sediments that are preserved should be examined at a level of intensity that is inversely proportional to their occurrence on the landscape” (Blum, 1989: 106). In other words, it is not enough to consider geomorphic patterns during or after archaeological survey, but use them to develop subsurface archaeological reconnaissance strategies central to research design.

Understanding the soil and sediment archives and their spatial-temporal erosional and depositional patterns in the region is a crucial step for assessing the presence and absence of prehistoric cultural activities. Investigations at the Lubbock Lake Landmark (Johnson, 1987), and elsewhere on the Southern High Plains, have identified intact buried archaeological assemblages and surface sites with diagnostic artifacts (e.g., projectile points, ceramics) that span the past ~12,000 years B.P. (Johnson, 2008; Johnson and Holliday, 2004). Archaeological evidence from the western Rolling Plains indicates people inhabited the region since ~10,800 B.P. Given that humans have been occupying the region continuously since ca. 12,000 B.P., understanding spatial-temporal landscape patterns is a key to assessing disproportional archaeological evidence from different cultural periods, i.e. archaeological preservation bias. Furthermore, understanding the spatial-temporal patterns allows archaeologists to create informed research designs, and aid in targeting archaeological surveys to specific periods. However, little is known about the soil and sediment fills within the canyonlands themselves compared to the adjacent regions, except for two studies initiated by cultural resource management (CRM) projects (i.e. Boyd, 1997; Quigg et al., 2010). In this paper, we present observations based upon extensive field study and radiocarbon ages, contribute new landscape evolution and soil stratigraphic results to an understudied dynamic and erosive landscape, and discuss how the landscape in the region has evolved geomorphically. We reconstruct the spatial-temporal landscape patterns to understand preservation patterns of archaeological material, and identify areas for future archaeological reconnaissance.

2. Background

2.1 Geologic Setting

The Southern High Plains, also known as the Llano Estacado, overlies sand and gravel deposited by eastward-flowing streams after the Rocky Mountain uplift began about 75 million years ago (mya) (Gustavson et al., 1991). Between 75 and 5 mya, the High Plains was a zone of net aggradation of sediment shed off the uplifting Rockies (Nereson et al., 2013). The Ogallala Formation, which is the major High Plains aquifer and source of springs in the study area, aggraded between about 13 and 5 mya (Chapin et al., 2008; Cather et al., 2012). Following landscape stability around 5 mya, eolian fine sand and silt derived from the Pecos River Valley covered the coarse-grained alluvium. Subsequent pedogenesis formed a thick, resistant caliche caprock (petrocalcic horizon) that comprises the upper surface of the Ogallala Formation (Holliday, 1995). Inset into the Ogallala Formation is the Blanco Formation, a late-Pliocene lacustrine unit (Holliday, 1997). Blanketing the Ogallala Formation is the Blackwater Draw Formation comprised of Pleistocene eolian deposits and paleosols (Holliday 1989a). Interbedded with the Blackwater Draw Formation are locally defined lacustrine deposits of the Tule, Double Lakes, Tahoka, and Spring Creek formations (Evans and Meade 1945, Martin 1950, Holliday, 1995).

During the Pleistocene, headward erosion of the Brazos River's tributaries and retreat of the Ogallala Caprock Escarpment shaped the canyonlands and adjacent Rolling Plains (Gustavson and Simpkins 1989, Madole et al. 1991). Remnant mesas transition to the low relief hills of the Rolling Plains as the South Fork broadens and migrates laterally to the east (Blum et al., 1992). Differential erosion has exposed Upper Permian red siltstones (Quatermaster Formation) and Upper Triassic sandstones, conglomerates, and mudstones (Dockum Group). Triassic mudstone outcrops are visible at the base of cutbanks within the study area (Lehman and Chatterjee, 2005). The Spring Creek Formation, a large Plio-Pleistocene unit (Martin, 1950) is comprised of lacustrine clays, sands, and evaporites. The Spring Creek formation can be seen locally in profile and is a source of redeposited sediment within the study area.

The geologic formations and groups within our study area can be challenging to recognize and interpret. In many areas under the Blackwater Draw Formation, pedogenic processes have degraded the Ogallala caprock, making some contexts difficult to distinguish from Blackwater Draw sediments (Hirmas and Allen, 2007). Furthermore, discerning Plio-Pleistocene lacustrine deposits is problematic due to their similar lithology (Holliday, 1995). Because the geological setting is not always straightforward, observing and differentiating specific formations and their relative ages relies on intensive field observations and various lab determinations.

2.2 Late-Quaternary Climate

For this study, we focused on post-LGM (Last Glacial Maximum) soils and sediments younger than ca. 25,000 B.P. (uncalibrated). Paleoenvironmental evidence indicates the Southern Plains region was a C_3 (cool/temperate) grassland with less seasonality and more effective moisture than today (Humphrey and Ferring, 1994; Holliday, 1995; Johnson, 1987; Johnson, 1991). Thus, the Southern Plains environment of the late Pleistocene was cooler than today, and was dominated by a cool- and moist-adapted grassland that supported large megafauna, including mammoth, horse, camel, and bison that were hunted by Paleoindians (Johnson and Holliday, 2004).

A dramatic climate shift to cooler conditions occurred at the Pleistocene-Holocene transition (ca. 10,900-9,800 B.P.). The transition, referred to as the Younger Dryas Chronozone (YDC), is a climatic event first defined from Greenland ice cores (Anderson, 1997). The impacts on the stratigraphic records in the Great Plains vary through space and time (Holliday et al., 2011). While climate proxies from Great Plains buried soils demonstrate a coeval cooling event (Mandel, 2008; Haynes, 2008), the Plains may not have experienced the same dramatic shift as recorded from the northern latitudes (Meltzer and Holliday, 2010). For example, in the Southern Plains, stable carbon isotopes from soil organic matter indicate C_4 (warm/semiarid) grassland expansion and increasing summer temperatures during the YDC (Holliday, 2000a; Nordt et al., 2002). Thus, the Southern Plains during the YDC experienced a turnover in flora and fauna (i.e. megafauna extinction, short-grass expansion) as well as decreases in the water table (Holliday et al., 2011), all of which had some impact on hunter-gatherer subsistence strategies (e.g. Johnson, 2007, 2008) as evidenced, for example, by changes in stone tool technology (i.e. Folsom points).

In the midcontinent, an overall trend of increasing aridity defines the Holocene (10,000 B.P.-present). Fluctuations between moist and dry periods occurred during the early Holocene (ca. 10,000-8,000 B.P.), with an overall drying trend evident from soil, phytolith, and pollen records (Balinsky, 1998; Ferring, 2001; Holliday, 2000a; Cordova et al., 2011). During the middle Holocene (ca. 8,000-4,500 B.P.) a substantial increase in aridity, known as the Altithermal, began ca. 8,000 B.P.; the most extreme xeric conditions occurred between 6,000-4,500 B.P. (Holliday, 1989b). On the Southern High Plains, the late Holocene (4,500 to present) was more mesic with periodic episodes of more xeric conditions, with increased aridity and episodic droughts beginning around 2,000 B.P. (Johnson and Holliday, 2004; Johnson 2007, 2008), including additional evidence for increased aridity after 1,000 B.P. (Holliday, 1995). However, in north-central Texas, an episode of drying occurred between 2,000-1,000 B.P., followed by a return to moist conditions after 1,000 B.P. (Humphrey and Ferring, 1994). Based on paleoenvironmental evidence from the Rolling Plains of western Oklahoma, a higher water table occurs between ca. 2,000 and 1,000 B.P. (Hall and Linz, 1984) and five mesic periods based on episodes of soil formation between 2,100 B.P. and 300 B.P. (Thurmond and Wyckoff, 1999, 2004). More inter-regional variations in environmental changes likely occurred during the late Holocene due to local storm patterns (Holliday, 1995). The current evidence across the Southern Plains demonstrates that the Holocene should not be viewed as a monolithic period of increasing aridity synchronous across the wide region; this concept can be tested by this study.

2.3 Archaeological Setting

Throughout the late Quaternary when climates were changing, cultures were changing as well. Prior to European contact ~250 years ago, prehistoric people of the Southern Plains were mobile hunter-gatherers with diverse lifeways and material culture (Perttula, 2004). The Southern High Plains archaeological record is divided into Paleoindian (11,500-8,500 B.P.), Early Archaic (8,500-6,000 B.P.), Middle Archaic (6,000-4,500 B.P.), Late Archaic (4,500-2,000 B.P.), Ceramic (2,000-500), and Protohistoric (500-300 B.P.) periods (Johnson and Holliday, 2004). In general, the cultural periods are generalized according to broad changes in technology and subsistence strategy associated with changing flora and fauna. Cultural periods are further subdivided, often by regional cultural manifestations expressed in technology, i.e. distinctive projectile points (e.g. Clovis, Folsom, Plainview) (Holliday, 2000b; Johnson and Holliday, 2004).

For the canyonlands, which arguably offered a favorable environment rich with plant, lithic, and water resources between the High Plains and Rolling Plains for hunter-gatherers making seasonal rounds, different cultural expressions have led to different period classifications. The cultural periods of the canyonlands have been classified by Boyd (2004) as Middle Archaic (~6,000 to 4,000 B.P.), Late Archaic (4,000 B.P. to 1,500 B.P.), Late Prehistoric I (1,500 to 1,000 B.P.), Late Prehistoric II (1,000 to 500 B.P.), and Protohistoric (500 to 250 B.P.) (Boyd, 2004). We rely on the classification scheme of Johnson and Holliday (2004) that is based on more archeological evidence over a broader region. Nevertheless, notable archaeological differences between the canyonlands and the Southern High Plains seem to be (1) the lack of known stratified Paleoindian localities and (2) the lack of Archaic cultural chronology.

3. Study Area Setting

The study area is within ~34,000-hectares (~83,000-acres) of ranchland that encompasses the canyonlands and includes adjacent portions of the Southern High Plains and western Central Lowlands (Figure 1). The South Fork, a 4th order stream based on Strahler's (1964) classification, flows northwest to southeast through the study area, draining numerous low-order tributaries into the Double Mountain Fork to the east and into the Brazos River. Two major tributaries drain into the South Fork on the ranch: Spring Creek and Middle Creek (Figure 1). The ranchland has been continuously used for cattle grazing since the 1879, and portions of the land have been used for oil production since the 1930s. A smaller ~13,000-hectare (33,000-acre) area that is generally undisturbed by oil production was targeted for archaeological survey between 2007 and 2010 because a preserved surface expression of the cultural landscape has remained relatively unaltered. To date, a total of 225 archaeological sites have been recorded in the 13,000-hectare parcel. Some of the sites are exposed on eroding surfaces and are palimpsest assemblages. Others are intact, buried, stratified, and/or multiple-occupation sites. Of 225 sites, 24 have been excavated and 124 have been mapped at the surface. Diagnostic artifacts and radiocarbon dates from features indicate the study area was occupied from at least the Late Paleoindian (e.g., Hurst et al., 2008) through historic periods (10,000 B.P. - A.D. 1950).

The modern climate of the study area is continental and semi-arid. Summer droughts are common, and convective thunderstorms in the spring and summer produce short episodes of heavy rain that cause significant erosion. Mean annual precipitation is ~48 cm, but total annual precipitation can range from less than 13 cm to over 101 cm from year to year (Wendorf & Hester, 1975). Average January and July temperatures are 28°F [-2.2 °C] and 95°F [35 °C], respectively (Harragan, 1983; Bomar, 1995). Even during periods of summer drought, over 50 groundwater springs and seeps from the Ogallala aquifer are active along escarpment walls where the Ogallala Formation occurs. In other words, the study area is hot and dry today, and groundwater springs remain a perennial source of water (Brune, 1981).

The modern plant community of the study area is diverse and consists of a xeric-adapted C_4 short-grass prairie dominated by blue grama (*Bouteloua gracilis*) and buffalo grass (*Buchlöe dactyloides*) (Johnson, 2007; Wester, 2007). The edges of the escarpment and reentrant canyons contain abundant honey mesquite (*Prosopis glandulosa*) and Pinchot juniper (*Juniperus pinchotii*), as well as buckthorn (*Zizyphus obtusifolius*), and occasional cottonwoods (cf. *Populus*) are found in the stream valleys (Johnson, 2007). Fourteen species of native cacti and succulents occur, including prickly pear (*Oputina* sp.), yucca (*Yucca glauca*), and cholla (*Cylindroputina* sp. and *Grusonia* sp.) (USDA, 2010). In the western Central Lowlands, buffalo grass (*Buchlöe dactyloides)* and mesquite (*Prosopis glandulosa*) (Küchler, 1974) dominate the landscape, with occasional post oak *(Quercus stellata)* (Nixon and Muller, 1997) and juniper (*Juniperus pinchotii*). Thus, the plant communities vary across the physiographic boundaries within the study area and include a range of succulents, shrubs, and trees; the landscape is not simply dominated by short grasses.

4. Methods

4.1 Field Methods

Initial field investigation involved reconnaissance to identify late-Quaternary landforms and buried soils at natural cutbanks along Spring Creek, Middle Creek, South Fork, and their tributaries. To obtain a representative sample of the soils and sediments, we partitioned the landscape based on late-Quaternary landforms (e.g. uplands, alluvial terraces, colluvial/co-alluvial fans, playas, sandsheets). In other words, we targeted different landforms across the landscape to reconstruct late-Quaternary geomorphic history. Localities were named based on the tract of land (e.g. Macy, PLK), and numbered sequentially as they were discovered; if archaeological materials were present, a state trinomial was assigned. Next, we documented landforms and described the sediments and buried soils using lithologic and pedologic nomenclature after Soil Survey Division Staff (1996) and Schoeneberger et al. (2002). Stratigraphic unit designations were assigned based on field description and laboratory results for this study only; they are informal designations. Buried soils from top of the profile to bottom were numbered consecutively following the "b" in soil horizon nomenclature (Holliday, 2004). We collected soil and sediment samples at 17 localities across the study area, sampling 15 localities from natural cutbanks, and coring two localities with a Giddings hydraulic soil probe (Figure 2). Each locality was sampled stratigraphically (vertically) at 5 cm intervals.

4.2 Radiocarbon Chronology

To establish a landscape chronology, we carefully collected organic-rich sediments and soils and sent the samples for analysis at the University of Arizona Environmental Isotope Laboratory for radiocarbon (^{14}C) dating following standard pretreatment procedures based on Polach et al. (1973). Radiocarbon (^{14}C) dating of bulk soil organic matter (SOM) from buried soils (humate and residue fractions) allows temporal reconstruction of the landscape when collected with care to avoid contamination from modern carbon or bioturbated organic materials from overlying soils and sediments. Although humic acids may have a greater potential of younger contaminates (Haynes, 2008), due to parent material sources (detrital carbon inputs) and dynamic processes during pedogenesis (e.g. bioturbation, leaching), many sources of carbon contribute to the age of a soil. Despite potential problems and contamination by older and younger carbon, ages determined from SOM generally provide accurate time control, particularly in semi-arid environments (Holliday et al. 2008; Mandel, 2008). However, they must be interpreted in context. In general, ages determined on humates reflect minimum ages for the onset of pedogenesis and residue ages reflect the maximum age of burial (Mayer et al., 2008).

We report 95 new radiocarbon ages, 94 of which were determined on paired samples, from 15 stratigraphic sections or cores both in uncalibrated years B.P. and calibrated years B.P. in Table 1. Calibration to 1σ (68.2% probability) was performed with OxCal v4.2.3 (Bronk Ramsey, 2009) using the IntCal 13 atmospheric curve (Reimer et al., 2013). Eighty-three ages are reported from either bulk SOM residue or humates, 11 are AMS residue or humate ages, and one AMS age was determined on charcoal. In some cases, the paired sample did not contain sufficient humates, so only the residue age is reported. Variations in the radiocarbon ages were expected for the different SOM fractions (see Holliday et al., 1983), and some soil ages have better agreement than others. The oldest reported age from each soil was highlighted in Table 1; the fraction yielding the oldest age is for the most part, the humate fraction, but it depends on profile context. Thus, SOM ages determined in our study were compared with ages presented in other studies in the region, using caution and broad generalities, since direct age comparisons must consider the complexities of soils, site formation processes, and the diversity of dating methods (see Martin and Johnson, 1995). In the following discussion, radiocarbon ages are presented in uncalibrated years B.P. to enable comparison with uncalibrated radiocarbon ages presented in the literature.

4.3 Particle Size (Pipette Method)

Particle-size distributions, or the relative proportions of sand, silt, and clay, reflect geomorphic processes involved in landscape evolution. Distributions of grain sizes along with color and other lithologic features (e.g., bedding) assist the interpretation of sediment origin, deposition, and transport. Because the complex nature of colluvial and alluvial interfingering was difficult to discern in the field, we used lab-based particle-size distributions to inform our interpretations of the landscape.

The pipette method (USDA NRCS, 2004), based on Stokes' Law of gravitational settling rates, was used to determine grain-size distribution on the <2000 μm fraction. Samples consisting of greater than 90% sand were analyzed separately from the pipette procedure with a Ro-Tap sieve shaker. National soil standards of known particle-size distributions and two internal standards were used to verify unknown particle-size results by calibrating lab-run standard distributions of sand, silt, and clay to the NRCS national database. Textural classes for each profile or core are reported on the lithostratigraphic figures.

5. Results

Five general geomorphic surfaces were identified across the study area based on landscape position and elevation: Uplands, Eroding Slopes, High Terrace (T-2), Low Terrace (T-1), and Modern Floodplain (T-0) (Figure 2). Co-alluvial fans, i.e., fans comprised of sediment transported by alluvial and colluival processes (Cremeens and Lothrop, 2001; Cremeens et al., 2003), were located in disconformable positions against the eroding slopes. Lateral continuity of buried soils and surfaces were challenging to determine because of erosion and the discontinuous and dissected nature of the land surfaces. Nevertheless, radiocarbon chronologies confirmed our delineation of the landscape elements in relation with older late-Pleistocene/early-Holocene deposits deeply buried in the uplands, mid-Holocene deposits associated with eroding slopes and co-alluvial fans, and multiple late-Holocene soils exposed beneath the high terrace.

The following sections present the results of individual localities based on elevation and landform, beginning with the locality at the highest elevation (Upland Playa), and concluding with the terrace fills of the low-order tributaries of the South Fork. Localities are labeled on Figure 2.

5.1 Upland Playa

We took one soil core near the center of a small ~1.44 hectare upland playa (Macy Locality 1) adjacent to a multiple-occupation hunter-gatherer campsite (site 41GR719) with several shallowly buried FCR features of unknown age (Figure 2). The core revealed ~3.5 m of clay-rich soils overlying a thin layer (10 cm) of eolian sand on top of the Ogallala caprock (Figure 3). SOM from four gray and grayish-brown (10YR 5/1-5/2) Btkss horizons 1.1-2.6 m below surface, have textures ranging from silty clay to clay, exhibit prominent slickensides, and yielded radiocarbon ages between ~4060 and 8800 B.P. (Table 1). Distinct light brown mottling

(7.5YR 6/4) occurs 220 cm below surface in the Btkss3 horizon that dates to ~7350 B.P. Thus, the playa basin exhibits steady clay accumulation since ~8800 B.P.

5.2 Spring Creek

At Macy Locality 31 in the upper reach of Spring Creek, a series of laterally inset fills were identified and characterized from a cutbank profile and transect of four cores drilled through the High Plains surface (Figure 2, Figure 4a). Radiocarbon ages span the LGM in Core 4 (~22,305 B.P.) to the late Holocene in Core 1 and Profile A (~3,015 B.P.) (Table 1). One small piece of FCR in a buried soil (ABtkb1) dating to ~3015 B.P. was exposed in the cutbank profile 110 cm below surface (Figure 4b). Mammoth tarsals were exposed in a shallow road-cut near Core 4 in lacustrine deposits, upslope from the FCR. Thus, this locality was targeted for extensive geoarchaeological testing to provide additional context for the archaeological and paleontological remains.

Core 1, taken adjacent to the cutbank, revealed a moderately developed surface soil and four buried soils. Radiocarbon ages determined on SOM dated from buried soils 1, 2, and 4 range from ~4745 to 9820 B.P. (Figure 3, Table 1). Evidence of soil welding comes from the presence of common pedogenic (illuvial) clay films and carbonates. These features are common in buried soils 1, 2, and 3 and taper to few in soil 4. Buried soil 3 is represented by a truncated BCk horizon. The missing A and B horizons represent an erosional unconformity between buried soils 2 and 3. The surface soil is a sandy loam to sandy clay loam and buried soils 1-4 are clay loams.

Cores 2, 3, and 4 contain older packages of lacustrine sediments compared to Core 1 (Figure 3). No buried soils were found in cores 2 and 3, but a dated organic-rich clay deposit in Core 3, 1.7-1.8 m below surface, yielded an AMS residue age of ~15,075 B.P. Core 4 contains

~4.5 m of stratified lacustrine and palustrine deposits that overlie the Ogallala caprock and Blackwater Draw Formation and underlie a 2 m-thick eolian sandsheet (Unit IX). Bulk residue radiocarbon ages on organic-rich lacustrine deposits were ~19,625 at 3.75 m (Unit VIII) and ~22,305 at 480 cm (Unit V) below surface. The mammoth tarsals near Core 4 are associated with lacustrine deposits equivalent to Unit VII, 4 m below the top of the core, between the two dated lacustrine layers in Units VIII and V. Thus, the eroding mammoth tarsals corroborate the LGM ages of the sediments.

Downstream in middle Spring Creek, tucked against the eroding slopes, Macy Locality 100 contains an 80 cm-thick stratified lacustrine deposit between two packages of co-alluvial sediment at Profile A (Figure 2, Figure 5). The sediments dip to the west toward the main channel of Spring Creek. The co-alluvium exhibits subtle intermixing of fine and coarse grained very pale brown (10YR 8/2) sediments from upland sources. Four thin organic lenses were recorded at the top of fining-upward sequences in the co-alluvium. The lowermost lens at 2.3 m below surface yielded a humate age of ~10,630 (Table 1, Figure 6a). SOM from the gray (10YR 5/1) clay loam lacustrine deposit (Unit III) yielded radiocarbon ages ranging between ~10,630 and 10,730 B.P. The slightly inverted ages between the co-alluvium and lacustrine deposit can be explained by co-alluvial mixing of detrital carbon. An assortment of late-Pleistocene fauna elements, systematically excavated nearby at the same locality in a lithologically similar lacustrine deposit (Johnson et al., 2011), corroborate the general age-range. The stratigraphy is more complex at the excavation area of Macy Locality 100, and no cultural material was found with the faunal remains (see Johnson et al., 2011).

Downstream near a zero-order tributary of middle Spring Creek is an 8 m section with two soils (Macy Locality 20) buried by 1.3 m of poorly sorted pebbly loamy sand and fine-grained reworked lacustrine sediment (co-alluvium) (Figure 2, Figure 5). The A horizon and most of the B horizon of buried soil 1 (2Bkb1) have been stripped by erosion. Co-alluvium and the remnants of a B-horizon overlie buried soil 2 (2ABkb2) that dates to the mid-Holocene (7405 ± 50 B.P. AMS humates) (Figure 6b). Soil parent material appears to be reworked (co-alluvial) light gray (10YR 5/2) lacustrine sediment of the local Spring Creek Formation. Underlying the buried soils is a thick deposit of fine and coarse-grained, bedded co-alluvium.

Macy Locality 3 is a ~7.5 m-thick section along middle Spring Creek, downstream from Macy 20 (Figure 2, Figure 6c). No soils were identified in the core, but a continuous sequence of organic-rich layers yielded SOM ages ranging from ~5135 to 10,650 B.P. (Table 1; Figure 5). Fine and coarse sandy clay alluvium underlies a ~5.5 m-thick package of olive, gray, red, and black deposits of paludal clays with abrupt boundaries. Weakly-bedded strong brown (7.5YR 4/6) alluvium overlies the palustrine deposits. Charcoal recovered 57 cm below the surface yielded an age of 3104 ± 38. Testing around the core location revealed a weakly developed surface soil that does not occur at the coring locality.

5.3 Middle Creek

In the upper reaches of Middle Creek, buried soils in co-alluvium and lacustrine deposits exposed in a shallow draw date from the Pleistocene-Holocene transition to mid-late Holocene at two profiles (A and C) at PLK Locality 73 (Figure 2, Figure 7). Because of their different ages, Profiles A and C represent two different buried lacustrine/palustrine fills. Profile A has a truncated surface soil and three buried soils (Figure 8a). The co-alluvial deposits contain two buried sandy loam soils: one at a depth of 16 cm (Akb1) and the other at a depth of 76 cm (2Akb2). The top and bottom radiocarbon ages from buried soil 2 are ~8935 and ~8525 B.P., respectively (Table 1). Buried soil 3 (3Akb3) is dark to light gray (7.5YR 6/1 – 10YR 7/1) and developed in loam, clay loam, and sandy clay loam lacustrine sediments between 105 and 156+ cm below surface. SOM from 140-150 cm within the 3Bkb3 horizon yielded a humate age of ~10,260 B.P. There is an abrupt, wavy boundary separating the co-alluvium and underlying lacustrine sediments. Pale yellow (2.5Y 7/4) redoximorphic iron oxide mottles increase in frequency down the profile (3Bkb3 and 3Cb3 horizons), and goethite is common (3Cb3 horizon), reflecting cycles of wetting and drying and post-depositional water movement in the soil.

Downstream at Profile C, recent erosion exposed two buried soils (2ABkb1 and 2ABk1b2) at 16 and 70 cm below surface developed in gray (10YR 6/1 and 5/1) sandy loam lacustrine deposits. SOM from the lower 10 cm of buried soil 1 and the upper 10 cm of buried soil 2 yielded humate ages of ~4015 and ~6235 B.P., respectively (Figure 8b). Coarse carbonate lithoclasts derived from the Ogallala Formation were present throughout soil 2, indicating not all carbonate is pedogenic. However, there were many fine, medium, and coarse masses of identifiable secondary calcium carbonate, and some carbonate-coated siliciclastic pebbles. The presence of redoximorphic features throughout soil 2 indicates episodic wetting and drying.

At PLK Locality 39 (Figure 2), a tributary joining the middle reach of Middle Creek exposed a remnant of a 7 m-thick alluvial fill preserved at the foot of the valley wall. Two brown (10YR 5/3) to reddish brown (5YR 5/4) silt loam to silty clay loam buried soils (soils 2 and 3) are developed in the alluvium; soil 2 is welded to soil 3 (Figure 7, Figure 9a). Samples collected from the top of the Akb1, bottom of the Btkb1, and top and bottom of the Akb2 yielded SOM ages that date to the late Holocene (Table 1, Figure 7). Based on the ages, two episodes of landscape stability occur at ~2590 B.P. and ~500 B.P.

5.4 South Fork Low-order tributaries

Near the broad floodplain of the South Fork, a number of ephemeral low-order streams feed the South Fork. Erosion has removed the early- and mid-Holocene alluvium, but late-Holocene alluvium and associated soils are preserved at four cutbank localities (Figure 10). One of the localities, Macy Locality 126, contains shallowly buried stratified cultural deposits (site 41GR793).

At Macy Locality 5 (Figure 2), a 7 m-thick package of alluvium overlies the Dockum Formation. The lower 3 m of the alluvium consists of sand. A 1 m-thick sequence of three welded buried soils developed in fine-grained alluvium overlies the sand (Figure 9b). The buried soils are reddish brown (5YR 4/3 and 4/4) silt clay loam with thin, patchy clay films. The surface soil and buried soils 1 and 2 have been bioturbated, as indicated by common fine krotovina and horizon mixing. SOM from the upper 10 cm of buried soil 3 (3.65 m below surface)—the only zone that appeared to be relatively undisturbed and suitable for radiocarbon sampling—yielded an age of ~1505 B.P. (Table 1). A 3 m-thick unit of massive, stratified sand that rapidly aggraded mantles the soils. A weakly developed modern soil is at the surface (Figure 10).

At the Macy Locality 48 cutbank (Figure 2), a modern soil is developed in colluvium and two buried soils (2Akb1 and 2Akb2) are developed in alluvium (Figure 9c). The buried A horizons at 100 and 155 cm below surface are weakly developed and consist of brown and reddish brown (7.5YR 4/3 and 5YR 4/3) sandy loam. Many carbonate threads and nodules occur in the 2Akb1 and 2Akb2 horizons, and slickensides are present in the 2Bssb1 and 2Bssb2 horizons. The 2Bssb1 and 2Bssb2 horizons are weakly developed. The occurrence of slickensides is more related to the large quantity of expandable clays from clay-rich parent material. SOM from the upper and lower 10 cm of the 2Akb1 and 2Akb2 horizons yielded humate ages of ~785 and ~1335 B.P. and ~1225 and ~2070 B.P., respectively (Table 1). Thus, relative landscape stability has occured at ~1225 and ~785 B.P. (Figure 10).

A ~4 m-thick section (Macy Locality 44) exposed along a small tributary near the main South Fork channel exhibits two truncated buried soils (Profile B) adjacent to a channel fill with one truncated buried soil (Profile A) (Figure 2). The truncated A horizons of buried soils 1 and 2 in Profile B are brown and reddish brown (7.5YR 4/3 and 5YR 4/3) clay loam to sandy clay loam, and SOM from the upper 10 cm of these soil yielded humate ages of ~710 and ~1335 B.P., respectively (Figure 9c, Figure 10). The ephemeral tributary changed course and cut perpendicular to Profile B sometime after ~710 B.P., depositing channel fill of pebbly sand fining upward to clay-rich sediment. The truncated buried soil, represented by the Btb1 horizon 125 cm below surface at Profile A, is a reddish brown clay loam, and was not sampled for radiocarbon dating due to low organic content.

A ~3 m-thick terrace fill exposed in a cutbank near the South Fork channel at Macy Locality 126 contains four buried soils developed in fine-grained alluvium (Figure 2). The buried A horizons are reddish brown clay loam to silty clay loams (Figure 10). SOM from the upper 10 cm of the Akb1 horizon 46 cm below surface yielded a humate age of ~680 B.P., and SOM from the upper 10 cm of the Akb2 horizon 78 cm below surface dates to ~1380 B.P. (Table 1). SOM from the upper 10 cm of the ABkb3 horizon 93 cm below surface and the upper and lower 10 cm of the ABkb4 horizon yielded humate ages of ~1380, 1335, 2010 B.P., respectively. Thus, the landscape was relatively stable from about 2010 to 680 B.P., with pedogenesis keeping up with alluviation for about the past 2000 years B.P. No cultural materials were observed in the buried soils. However, charcoal recovered from one lithic concentration and five hearth (cooking) features ~15-30 cm below surface dated between ~300 and 700 B.P. (site 41GR793). The features are ~1x1 m^2 and lined with mostly caliche (Ogallala Formation) fire-cracked rocks. Two discrete hearth features were stratified; both contained the remains of charred bison bone. All five features were constructed on the terrace surface, above soil 2, before being shallowly buried by co-alluvial sandy clay loam after ~300 B.P.

6. Discussion

Despite the challenges associated with studying discontinuous landform sediment assemblages at the edge of a dramatic escarpment, we were able to identify fairly consistent spatial-temporal patterns for the study area. Geomorphic processes are working to preserve or erode late-Quaternary landforms and associated soils and archaeological deposits at localities throughout the study area; sediments are removed or deposited in patterns that are similar to patterns identified in other studies in the region.

Unlike other discontinuous landforms that occur throughout the canyonlands, one upland playa (Macy Locality 1) shows a steady accumulation of lacustrine clay beginning before ~8800 B.P. and continuing through the late Holocene. An abrupt boundary between the clays and a lens of sand at basin depth is consistent with what was found in larger systematic studies of playa fills on the Southern High Plains (Holliday et al., 1996; Holliday et al., 2008). Specifically, the evidence at Macy Locality 1 points to aridity and concomitant wind erosion during basin formation, followed by several millennia of basin aggradation under moist conditions with a higher water table and greater biomass since the early Holocene. Evidence of oxidation in the form of distinct mottles at ~2 m suggests a lower water table and drier conditions beginning ~7000 B.P. This situation is consistent with Holliday et al. (2008) and regional proxy records for increased aridity during the Altithermal (Holliday, 1989b, 1995, 2001; Johnson 1987, 2007).

In both the upper reaches of low-order Middle and Spring creeks near the surface of the Southern High Plains, older late-Quaternary sediments are preserved that have otherwise been removed downstream in the study area. A series of laterally inset fills at Macy Locality 31 dating from the LGM to the late Holocene were preserved as Spring Creek migrated eastward. In the upper reaches of Middle Creek, erosion in a shallow draw at PLK Locality 73 is beginning to expose dark, organic-rich buried soils dating to the Pleistocene-Holocene transition developed in lacustrine deposits observed in Profile A. Younger organic-rich mid- to late-Holocene soils that developed in lacustrine deposits also are exposed nearby in Profile C.

Within middle Spring Creek, two co-alluvial fans on footslopes reveal landscape instability and sedimentation at the onset of early-Holocene aridity. At Macy Locality 100 (Profile A), a lacustrine deposit dating to the YDC was buried beneath a co-alluvial fan that began to aggrade soon after 10,800 B.P. At Macy Locality 20, over 6 m of co-alluvium accumulated before a brief period of soil formation at ~7405 B.P. Based on field observations and grain-size analysis, sediments at both fans were transported by a combination of gravity and water. Both fans contain reworked lacustrine sediments, likely from Plio-Pleistocene lake beds that once comprised the Spring Creek formation (Evans and Meade, 1945).

Within middle Spring Creek, Macy Locality 3 is distinct because of the continuous record of a ~5.5 m package of olive, gray, red, and black paludal clays that rapidly aggraded since ~10,700 B.P., perhaps due to proximity near an Ogallala aquifer spring source. The accumulation of clay slowed by 9000 B.P. and continued to aggrade at a slow rate until about ~5000 B.P.—consistent with increasing aridity during the mid-Holocene—before being buried by alluvium.

Downstream in zero-order draws near the South Fork floodplain and within the T-2 terrace sediment assemblage, a late-Holocene pedocomplex preserved at multiple localities ranges in age from ~2800 to 600 B.P. The late-Holocene pedocomplex was observed mostly in cutbanks that exposed T-2 fill near the South Fork. It also, however, was recorded at one cutbank locality, PLK 39, where a remnant of the T-2 terrace is preserved on the margin of the valley floor of a zero-order tributary of Middle Creek. The late-Holocene buried soils that occur across the study area are similar in age and represent two major soil-forming periods: one beginning around 2500 to 2000 B.P., and another beginning around 1300 to 1200 B.P. Soil development ceased around 600 B.P. Recent colluvial, alluvial, and eolian deposits have since buried these late-Holocene soils and thin, weakly developed soils have developed in these sediments at the modern surface of the T-2 terrace.

Episodes of stability marked by soil formation are well documented across the Southern Plains and are generally contemporaneous with the study area. At the end of the middle Holocene, evidence for prolonged landscape stability on the Southern High Plains is marked by the thick Lubbock Lake Soil that developed in marsh sediments. Pedogenesis continued until about 1,000 B.P. (Holliday and Allen, 1987; Holliday, 1995). In southwestern Kansas, two late-Holocene soils, the Hackberry and Buckner Creek paleosols, have been reported (Mandel, 1994). The Hackberry Creek soil began aggrading ~2800 B.P., stabilized by ~2600 B.P. and was buried around 2000 B.P. The Buckner Creek soil began aggrading ~1500 B.P. and was buried around 1000 B.P. A cumulic soil, referred to as the Copan paleosol (Hall and Linz, 1984; Hall, 1990), has been documented across north-central Texas and northeastern and southwestern Oklahoma. Here, pedogenesis was keeping up with alluviation in a quasi-stable environment under region-wide wetter-than-today climatic conditions between ~1900 and 960 B.P. (Carter et al., 2009).

Within the study area, two preserved late-Holocene soils exhibit landscape stability and more mesic climate (more rainfall, soil moisture, and vegetation cover) beginning around 2500

B.P. and 1300 B.P. No evidence is noted for substantial drying after 1000 B.P. as occurs on the Southern High Plains (Holliday, 1995). Instead, soil formation in the study area is similar to soils reported from the southern margin of the Central Plains in southwestern Kansas (Mandel, 1994), and may correspond to some of the wetter periods reported from the Southern Plains of western Oklahoma (Thurmond and Wyckoff, 1999, 2004).

6.1 Archaeological Implications

The past 30 years of geoarchaeological research in the Plains has established that climate-driven geomorphic processes filter the archaeological record (e.g. Ferring 1990, 1995; Holliday 1995, 1997; Blum et al., 1992; Bettis and Mandel, 2002; Mandel, 1992, 1994, 1995, 2006, 2008; Beeton and Mandel, 2011). Therefore, the discovery of cultural materials associated with specific periods is dependent on the age of the landform surveyed. The age of a landform sediment assemblage is dependent on the position in the landscape and stream order within a drainage basin (Mandel, 1992, 1994). To this end, few early sites with stratified cultural deposits have been recorded within the canyonlands, while younger Late Archaic through Protohistoric campsites are relatively common and visible on exposed late-Holocene geomorphic surfaces (Quigg et al., 2010). One exception is the Lake Theo site about 160 km north of the study area, and 10 km east of the Caprock escarpment in the Red River drainage (Harrison and Killen, 1978; Holliday, 1997). At Lake Theo, which is in the valley of a low-order stream, Folsom and Plainview components consisting of the butchered remains of *Bison antiquus* occur in the A horizon of a paleosol 3-4 m below the surface of a terrace (Holliday, 1997). Isolated Paleoindian (e.g. Clovis) points have been found on the surface with and without context within the study area. For example, one Late Paleoindian site, Macy Locality 15, consists of one unfluted, basally thinned point made of local Ogallala Formation chalcedony and a small chipped-stone assemblage on the surface of a remnant terrace overlooking the South Fork (Hurst et al., 2008).

The stream valleys of the Central Plains or the draws just to the west on the Southern High Plains contain deeply buried landscapes dating to the Pleistocene-Holocene transition (Holliday, 1995; Mandel, 2008). Preservation or deep burial of late-Pleistocene and early-Holocene sediments seem less-likely in the canyonlands due to the abundance of low-order drainages, and the high erosion rates and heavy dissection and removal of terrace fills. Nevertheless, organic-rich YDC soils and sediments have been found at a number of locations across the study area either high in the drainage network near the Southern High Plains, or buried by mid-Holocene co-alluvial fans at valley wall footslopes. The properties and exact timing of YD age soils vary across the midcontinent, particularly in the Great Plains. These soils, however, are an important stratigraphic, climatic, and archaeological marker that should be explored further within the canyonlands.

Based on information gleaned from the series of cores in the upper reaches of Spring Creek at Macy Locality 31, mammoth tarsals eroding from the access road are not cultural deposits. However, the area surrounding Macy 31 should be targeted for additional paleontological discoveries. Fire-cracked rock (FCR) discovered in Soil 2 in the Macy 31 cutbank profile probably is associated with Late Archaic activities, but excavation units here would help determine that association. This soil can be traced to other sections of the study area where it is exposed on eroding slopes and where numerous FCR or thermal cooking features (e.g. hearths) have been documented during archaeological survey. Understanding the spatial pattern of this soil and how it is being eroded across the study area is important for accurately interpreting site location and human behavior.

7. Conclusions

The eastern edge of the Llano Estacado, known as the Caprock Canyonlands or Escarpment Breaks, is a distinct physiographic and dynamic region that presented challenges in systematically discerning the landscape evolution and locating buried soils of specific ages. Despite the dynamic landscape that is a product of intensive erosion on the steep slopes of the escarpment edge, net sediment storage occurred in low-order drainages during the late Holocene. This process resulted in burial of soils and cultural deposits. A similar pattern of sediment storage has been reported for the Central Plains (see Mandel, 1992, 1994, 1995, 2006; Bettis and Mandel, 2002; Beeton and Mandel, 2011). Because the low-order streams that dominate the study area were zones of net sediment removal during the early and middle Holocene, a paucity exists of available valley fills dating between ca. 10,000 and 4,000 B.P. However, early and middle Holocene sediments are preserved in co-alluvial fans along the margins of valley floors. Also, sediments and soils dating to the Pleistocene-Holocene transition occur high in the drainage network (about 150 m above the South Fork valley floor) near the Southern High Plains surface, or are buried by co-alluvium near the eroding slopes of valley walls. These areas are particularly important targets for future archaeological reconnaissance since *in situ* Paleoindian cultural materials are extremely rare within the canyonlands.

The spatial-temporal patterns detected in our study are similar to patterns reported by Blum et al. (1992) for the area directly downstream in the Double Mountain Fork of the Brazos River within the western Rolling Plains, corroborating the significant impact of geomorphic filtering on archaeological sites. Building from the original observations of Blum et al. (1992) and extending the model into the steep slopes of the escarpment edge raises some important questions, and underscores the need for further evaluation of the Blum (1989) conceptual model.

With so much sediment removed from the canyonlands, the inversely proportional subsurface prospecting recommended by Blum (1989) is not the best solution, nor is it cost-effective for locating under-represented archaeological periods in their original context. This is particularly relevant for prospecting in the eroding slopes, where a palimpsest of Middle Archaic through Protohistoric-age material has been documented in the study area. In this context, efforts must be made to evaluate site formation and preservation, quantify the volume of material lost, and assess bias by extrapolating some number for 'lost' archaeological sites. Although vertical survey of cutbank exposures remains an effective and efficient means of discovering buried soils, well-preserved archaeological sites, and other stratigraphic deposits of paleoecological interest, the next steps include the accurate quantification of erosion and the geomorphic bias inherent in highly modified areas. Such integrated methodologies are crucial to evaluating human site selection, migration patterns, and demographics—and underscore the broad utility and impact of integrated geoarchaeological research and landscape archaeology.

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Table 1. Radiocarbon ages determined on soil organic matter for the study area, listed by drainage and locality.

Locality	Context	Soil Horizon/ Informal Strat. Unit	Material Assayed [a]	Sample Depth (cm)	^{14}C age (yr. B.P.)	Cal age (yr. B.P.)[b]	$\delta^{13}C$	Lab. No. [c]
High Plains Playa								
Macy 1 Core	Playa fill	Btkss1	SOM (r)	110-120	3495 ± 65	3847-3649	-19.7	A15965
			SOM (h)		**4060 ± 125**	**4813-4419**	-17.8	A15965.1
		Btkss2	SOM (r)	130-140	3345 ± 130	3817-3410	-19.5	A15966
			SOM (h)		**4345 ± 120**	**5275-4825**	-18.3	A15966.1
			SOM (r)	150-160	4310 ± 85	5041-4730	-19.2	A15967
			SOM (h)		**4625 ± 140/135**	**5579-5062**	-17.8	A15967.1
			SOM (r)	170-180	5360 ± 100	6275-6006	-19.2	A15968
			SOM (h)		**5560 ± 180/175**	**6618-6183**	-17.7	A15968.1
		Btkss3	SOM (r)	190-200	6775 ± 115/110	7733-7513	-19.2	A15969
			SOM (r)	210-220	7375 ± 160/155	8340-8042	-19.1	A15970
			SOM (h)		7320 ± 200/195	8340-7973	-19.0	A15970.1
		Btkss4	SOM (r)	230-240	7567 ± 140	8516-8203	-19.6	A15971
			SOM (r)	245-255	8800 ± 145	10,147-9662	-19.6	A15972
Spring Creek (upper)								
Macy 31, Profile A	Uplands	ABtkb1	SOM (r)	70-80	2530 ± 120/115	2753-2465	-16.2	A15204
			SOM (h)		**3015 ± 135**	**3364-3007**	-15.3	A15204.1
		Btb1	SOM (r)	110-120	5070 ± 110	5919-5664	-16.4	A15205
			SOM (h)		**5810 ± 265/260**	**6930-6319**	-17.5	A15205.1
Macy 31, Core 1	Uplands	ABtkb1	SOM (r)	105-115	3400 ± 190/185	3895-3414	-17.2	A15416
			SOM (h AMS)		**4745 ± 40**	**5583-5334**	-15.8	A15416.1
		ABtkb2	SOM (r)	170-180	7240 ± 145/140	8277-7932	-15.6	A15417
			SOM (h AMS)		**8155 ± 40**	**9129-9021**	-17.3	A15417.1
		ABtkb4	SOM (r)	220-230	8385 ± 205/200	9545-9091	-18.2	A15418
			SOM (h AMS)		**9820 ± 45**	**11,249-11,203**	-17.7	A15418.1
Macy 31, Core 3	Uplands	Cg2	**SOM (r AMS)**	170-180	**15,075 ± 65**	**18,435-18,222**	-19.8	A15419
			SOM (h AMS)		14,235 ± 75	17,463-17,210	-17.9	A15419.1
Macy 31, Core 4	Uplands eolian,lacustrine	Unit VIII	SOM (r)	375-385	19,625 ± 520/485	24,244-23,034	-18.0	A15420
		Unit V	SOM (h AMS)	480-490	19,250 ± 120	23,373-23,015	-16.8	A15421.1
			SOM (r)		**22,305 ± 1145/1000**	**27,760-25,700**	-17.7	A15421
Spring Creek (middle)								
Macy 100, Profile A	Eroding Slopes co-alluvial fan & lacustrine	Unit IV	SOM (r)	230-231	10,280 ± 140	12,385-11,812	-23.2	A15795
			SOM (h)		**10,630 ± 150/145**	**12,715-12,417**	-22.2	A15795.1
		Unit III	**SOM (r)**	265-275	**10,630 ± 160/155**	**12,725-12,389**	-17.6	A15796
			SOM (h)		10,300 ± 245/240	12,528-11,710	-18.1	A15796.1
			SOM (r)	295-300	9920 ± 155/150	11,704-11,203	-17.7	A15797
			SOM (h)		**10,605 ± 570/535**	**13,071-11,649**	-17.9	A15797.1
			SOM (r)	335-345	10,280 ± 175/170	12,410-11,760	-18.1	A15798
			SOM (h)		**10,730 ± 260/250**	**12,986-12,246**	-17.7	A15798.1
Macy 20	Eroding Slopes co-alluvial fan	2ABkb2	SOM (r)	165-170	7355 ± 70	8295-8048	-14.2	A15048
			SOM (h AMS)		7405 ± 50	8310-8180	-14.5	A15048.1
Macy 3	Eroding Slopes co-alluvial fan with lacustrine and palustrine	Unit III	Charcoal (AMS)	57-58	3104 ± 38	3372-3252	-22.4	AA78638
		Unit II	SOM (r)	76-81	5135 ± 145/140	6171-5664	-20.9	A14886
			SOM (h AMS)		**7370 ± 45**	**8305-8063**	-18.3	A14716
			SOM (r)	125-134	6735 ± 50	7655-7569	-18.0	A15831
			SOM (r)	136-138	7600 ± 470/445	9006-8006	-24.3	A14726
			SOM (h)		**9235 ± 215/210**	**10,751-10,188**	-18.0	A14727
			SOM (r)	156-170	**9950 ± 120/115**	**11,619-11,241**	-17.8	A14887
			SOM (h AMS)		9840 ± 55	11,280-11,200	-18.8	A14886.1
			SOM (r)	170-182	9625 ± 85	11,167-10,793	-18.0	A14800
			SOM (r)	210-225	10,170 ± 145/140	12,094-11,410	-19.4	A14801

			SOM (r)	328-331	10,120 ± 530/495	12,576-11,185	-18.3	A14888
			SOM (h AMS)		**10,320 ± 60**	**12,377-12,019**	-29.0	A14888.1
			SOM (r AMS)	401-404	**10,370 ± 55**	**12,386-12,133**	-20.7	A14724
			SOM (h)		10,145 ± 330/315	12,376-11,269	-20.0	A14725
			SOM (r)	655-660	10,650 ± 225/220	12,576-12,170	-15.7	A14889
Middle Creek (upper)								
PLK 73, Profile A	Eroding Slopes eolian/colluvial and lacustrine	2Akb2	SOM (r)	76-86	6545 ± 235/230	7668-7183	-19.4	A15049
			SOM (h)		**8935 ± 120**	**10,230-9889**	-19.4	A15049.1
			SOM (r)	86-96	7635 ± 120	8560-8343	-19.4	A15050
			SOM (h)		**8525 ± 225/220**	**9888-9267**	-19.1	A15050.1
		3Bkb3	SOM (r)	140-150	9880 ± 135	11,611-11,182	-22.7	A15051
			SOM (h)		**10,260 ± 315/305**	**12,522-11,412**	-19.5	A15051.1
PLK 73, Profile C	eolian/colluvial and lacustrine	2BCkb1	SOM (r)	60-70	2555 ± 80	2756-2493	-16.5	A15053
			SOM (h)		**4015 ± 175/170**	**4814-4258**	-16.4	A15053.1
		2ABk1b2	SOM (r)	70-80	4878 ± 100/95	5737-5480	-18.0	A15052
			SOM (h)		**6235 ± 185/180**	**7408-6911**	-18.1	A15052.1
PLK 39	T-2 alluvial	Akb1	**SOM (r)**	62-72	**685 ± 60/55**	**684-563**	-17.9	A15101
			SOM (h)		500 ± 35	540-510	-18.3	A15101.1
		Btkb1	SOM (r)	105-115	1075 ± 100	1173-914	-16.8	A15102
			SOM (h)		**1635 ± 150**	**1704-1383**	-17.2	A15102.1
		Akb2	SOM (r)	157-167	1815 ± 110	1870-1616	-16.1	A15103
			SOM (h)		**2590 ± 170/165**	**2842-2490**	-16.0	A15103.1
			SOM (r)	190-200	2350 ± 115/110	2697-2181	-15.6	A15104
			SOM (h)		**2865 ± 40**	**3060-2929**	-17.4	A15104.1
South Fork (low-order trib.)								
Macy 5	T-2 alluvial	4ABtkb3	**SOM (r)**	365-375	**1505 ± 35**	**1474-1340**	-17.1	A15047
			SOM (h)		1350 ± 120/115	1388-1095	-18.2	A15047.1
Macy 48	T-2 alluvial	2Akb1 (top)	SOM (r)	100-110	745 ± 75	758-567	-17.8	A15108
			SOM (h)		**785 ± 80/75**	**788-668**	-18.4	A15108.1
		2Akb1 (bottom)	SOM (r)	120-130	1000 ± 70	974-797	-18.1	A15109
			SOM (h)		**1335 ± 105/100**	**1354-1096**	-19.1	A15109.1
		2Akb2 (top)	**SOM (r)**	155-165	**1225 ± 65**	**1255-1070**	-17.9	A15110
			SOM (h)		1170 ± 125/120	1236-965	-19.6	A15110.1
		2Akb2 (bottom)	**SOM (r)**	200-210	**2070 ± 100**	**2153-1899**	-18.3	A15107
			SOM (h)		1400 ± 130/125	1523-1266	-18.5	A15107.1
Macy 44, Profile B	T-2 alluvial	ABkb1	SOM (r)	100-105	670 ± 50	674-562	-18.3	A15106
			SOM (h)		**710 ± 85**	**728-561**	-18.5	A15106.1
		ABkb2	SOM (r)	110-120	1085 ± 65	1060-932	-16.9	A15105
			SOM (h)		**1355 ± 100**	**1370-1178**	-17.4	A15105.1
Macy 126, Profile A	T-2 alluvial	Akb1	SOM (r)	46-55	605 ± 50	650-549	-17.3	A15411
			SOM (h)		**680 ± 85**	**689-555**	-18.0	A15411.1
		Akb2	SOM (r)	78-88	1085 ± 70	1067-927	-15.9	A15631
			SOM (h)		**1380 ± 100**	**1389-1163**	-17.0	A15631.1
		ABkb3	SOM (r)	93-107	1340 ± 55	1305-1184	-16.1	A15412
			SOM (h)		**1380 ± 100**	**1389-1183**	-17.6	A15412.1
		ABkb4	SOM (r)	148-158	1275 ± 50	1278-1179	-16.1	A15639
			SOM (h)		**1335 ± 45**	**1301-1187**	-17.2	A15639.1
			SOM (r)	168-178	1990 ± 55	1996-1880	-16.3	A15640
			SOM (h)		**2010 ± 130**	**2141-1823**	-17.0	A15640.1

[a] SOM = Soil Organic Matter conventional ages determined on soil residue (r) and soil humates (h) unless otherwise indicated as AMS.
[b] Calibration to calendar years at 1 σ (68.2% probability) was performed with OxCal v4.2.3 (Bronk Ramsey, 2013) using calibration dataset IntCal 13 (Reimer et al., 2013).
[c] Radiocarbon laboratory numbers: A = University of Arizona

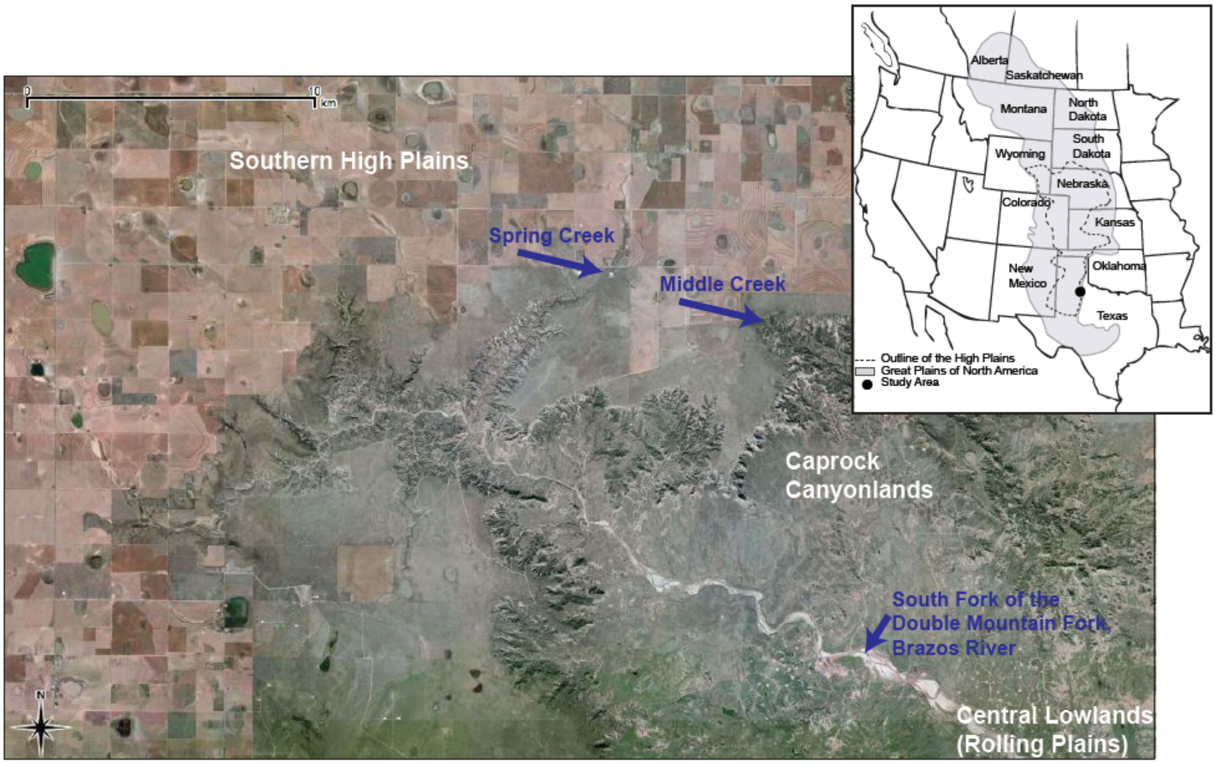

Figure 1. Map of physiographic provinces and streams within study area.

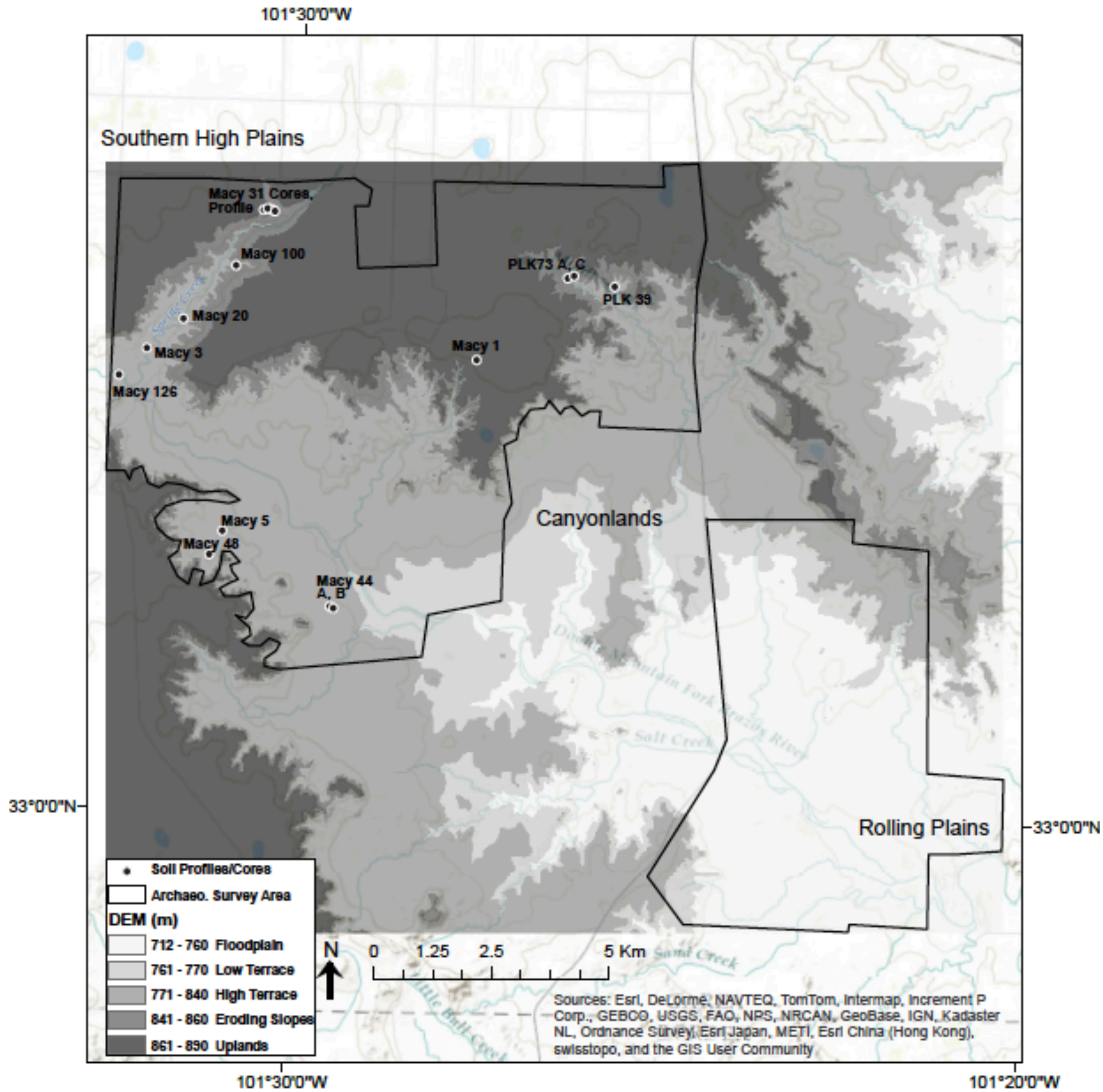

Figure 2. Map of the study area showing shaded elevations based on landform surfaces, the outline of the archaeological survey areas, and all profile or core localities presented in the text. Three localities, Macy 31, PLK 73, and Macy 44 are represented by multiple cores or profiles.

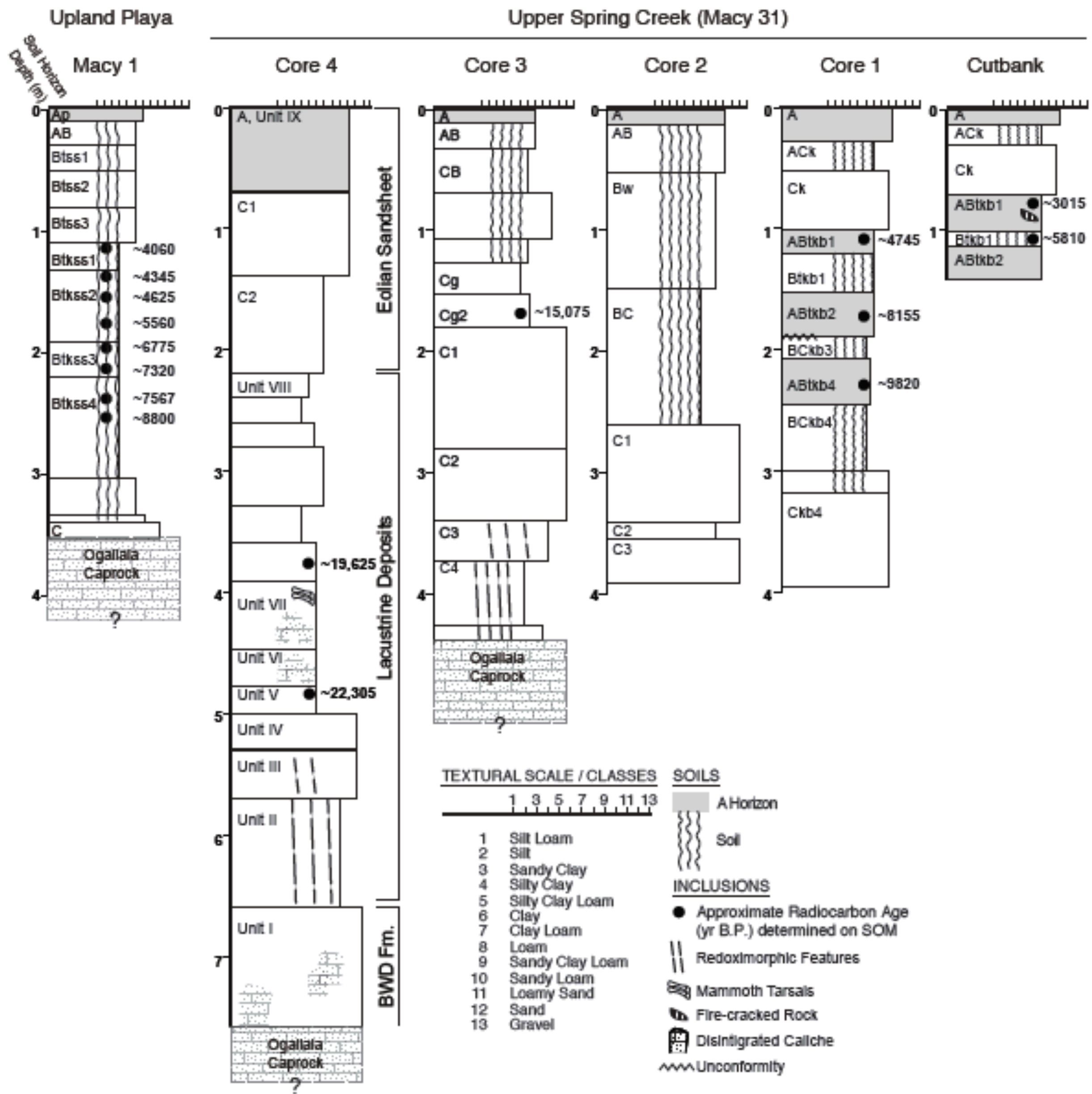

Figure 3. Schematic stratigraphic diagram for Macy Localities 1 and 31 near upper Spring Creek.

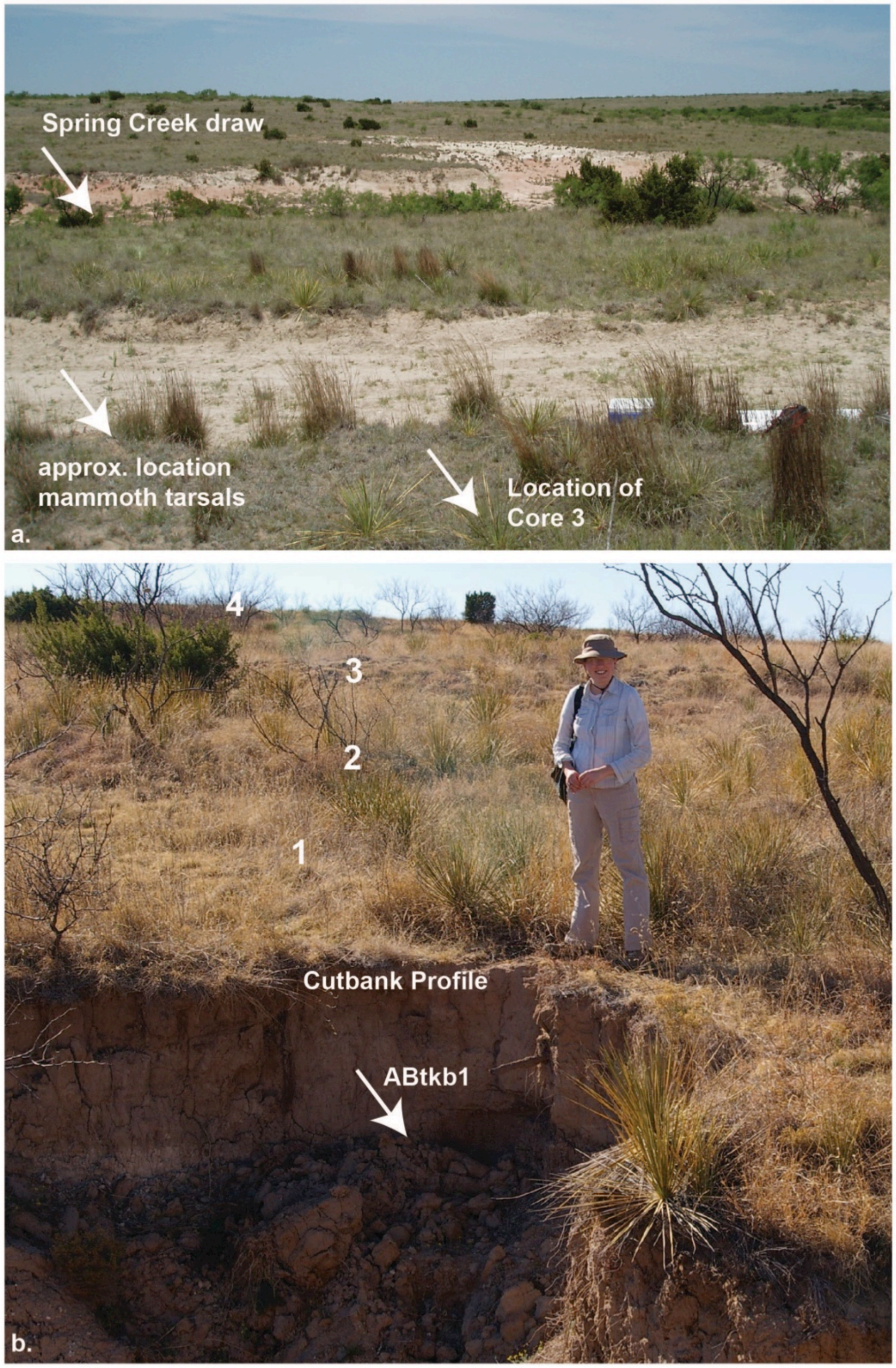

Figure 4. Photographs of Macy Locality 31 near upper Spring Creek.

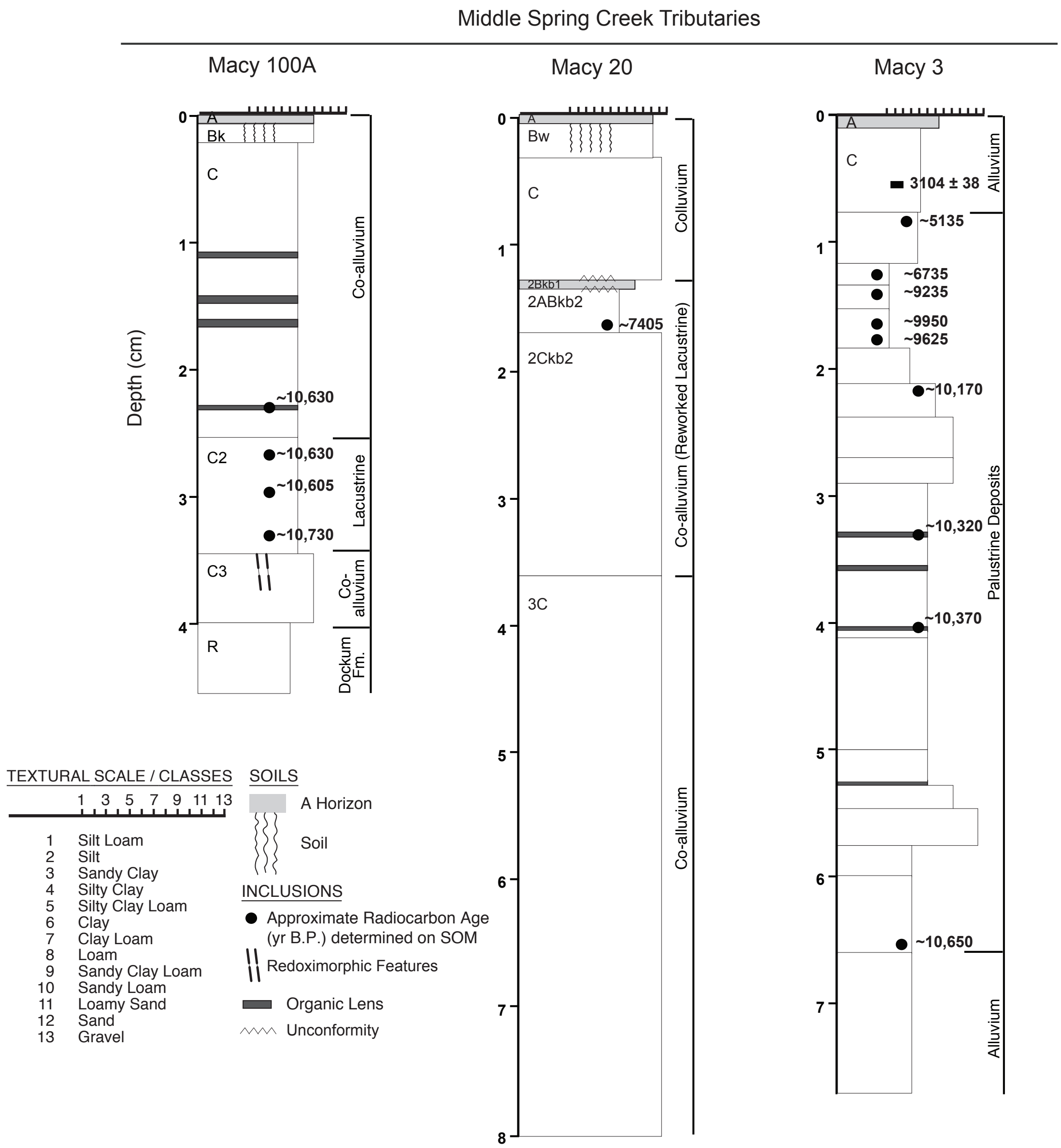

Figure 5. Schematic stratigraphic diagrams for middle Spring Creek including Macy Localities 100, 20, and 3.

Figure 6. Photographs of Macy Localities 100, 20, and 3 within middle Spring Creek.

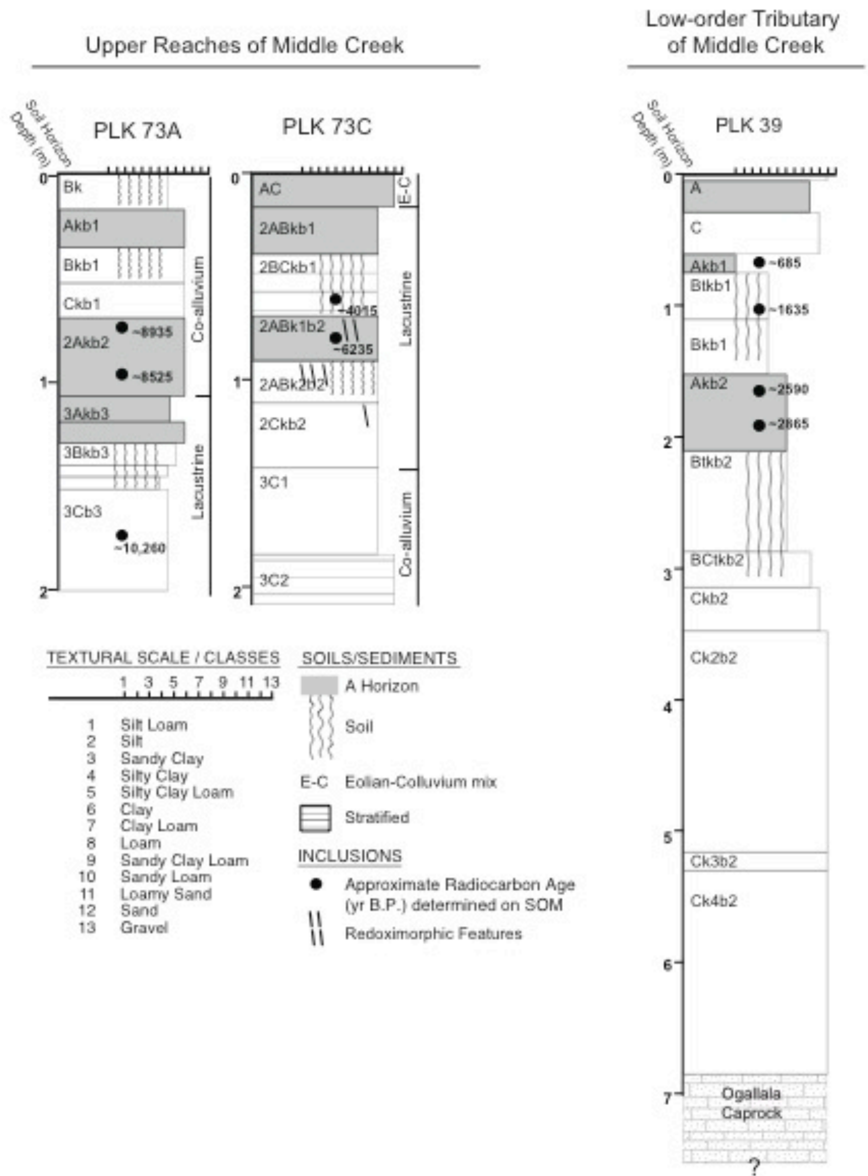

Figure 7. Schematic stratigraphic diagrams for Middle Creek localities PLK 73 and 39.

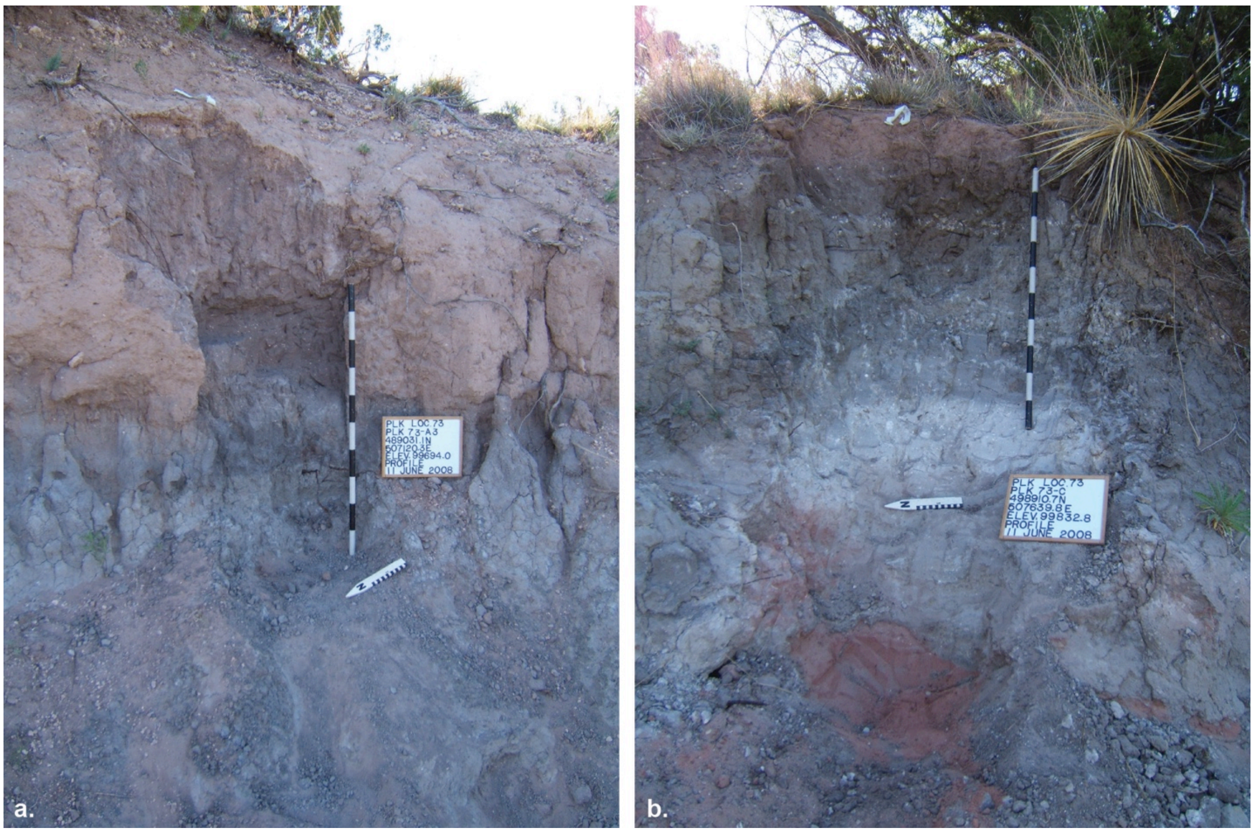

Figure 8. Photographs of the soil profiles from PLK Locality 73 A and C.

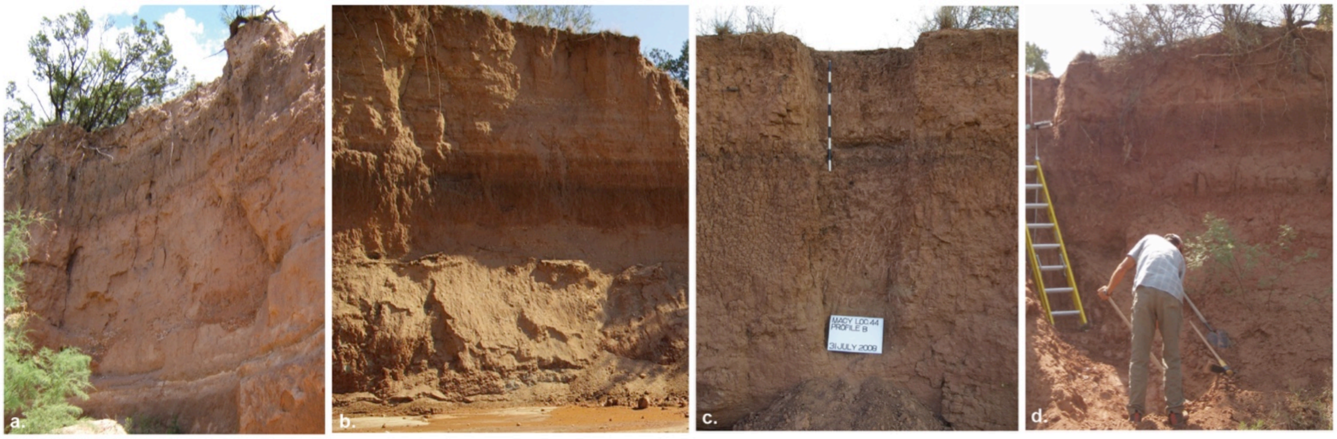

Figure 9. Photographs of Late Holocene soils for profiles at Macy Localities 5, 44, and 48 in tributaries of the South Fork.

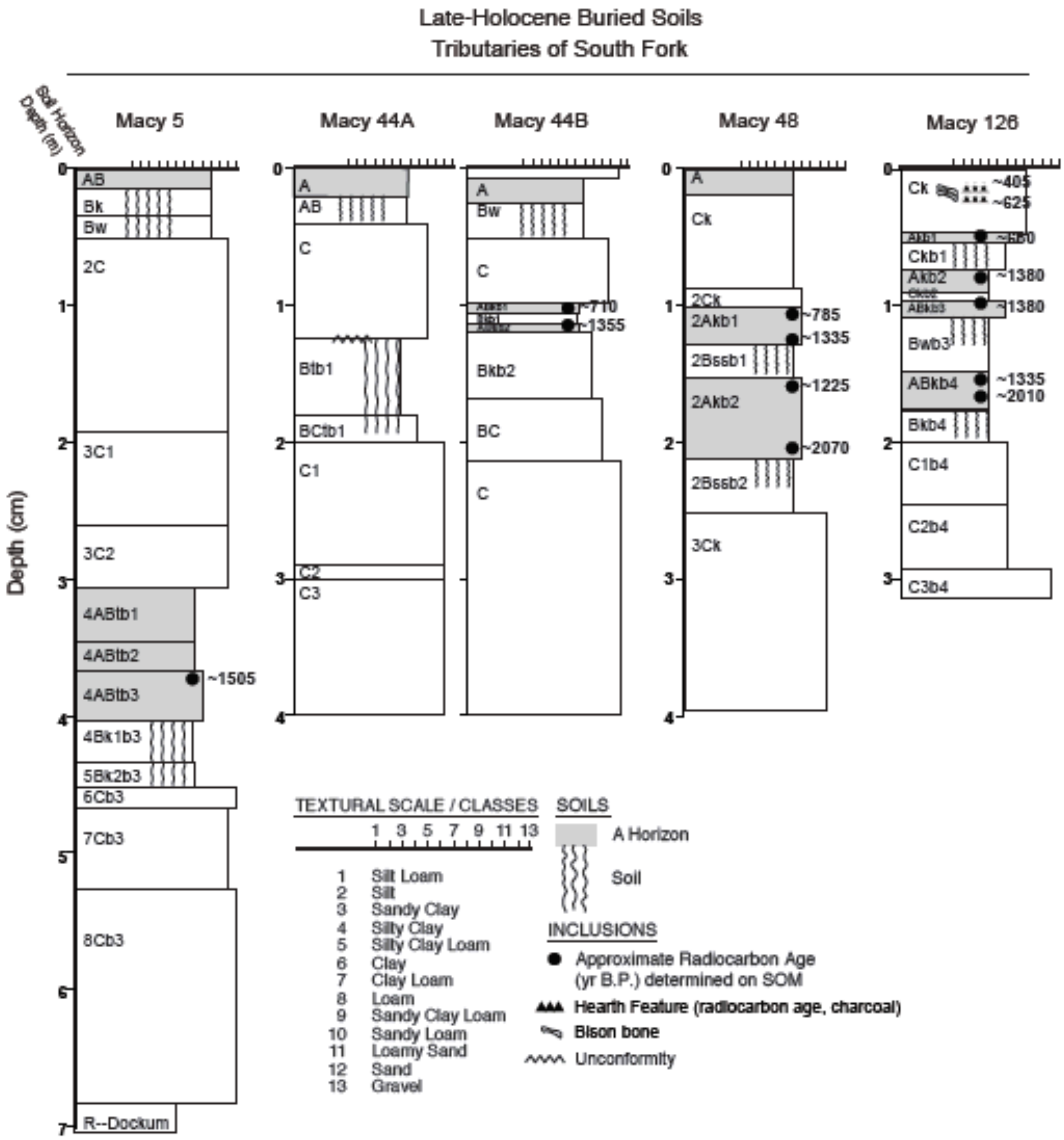

Figure 10. Schematic stratigraphic diagram for Late Holocene soils at Macy Localities 5, 44, 48, and 126.

CHAPTER 3

Submitting to *Quaternary Research* as:

Multiple Proxy Paleoenvironmental Data from the Eastern Escarpment of the Southern High Plains of Texas: Implications for Archaeological Research

Laura R. Murphy, Stance C. Hurst, and Eileen Johnson

Abstract

New multiple-proxy paleoenvironmental data are presented from the soil and sediment archives of tributaries of the South Fork of the Double Mountain Fork of the Brazos River near the edge of the eastern Ogallala caprock escarpment in northwest Texas. Soil, stable carbon isotope, and microbotanical (phytoliths and diatoms) data are compared the regional record. At Middle Creek, buried soils in lacustrine and co-alluvial deposits ranging from ca. 10,300-8900 ^{14}C yr B.P. (uncalibrated) contain well-preserved phytolith and diatom assemblages. Microbotanical analyses and stable carbon isotope values of soil organic matter suggest a cool/moist environment at the Pleistocene-Holocene transition, followed by a slight increase in aridity with seasonal wetting and drying. The most abundant diatom species, *Diadesmis gallica*, thrived ca. 10,300 B.P. near the edge of a shallow lake or marsh under a cooler climate than today. At Spring Creek, a series of laterally inset alluvial and palustrine fills spans ca. 22,000-3000 ^{14}C yr B.P. Stable carbon isotope results from upper Spring Creek indicate that the C_4 plant productivity has increased since the Last Glacial Maximum, but a C_3 and mixed C_3/C_4 plant community persisted in Holocene microenvironments. The multiple proxy data from late Holocene buried soils in alluvial fills along the South Fork also show that a mixed C_3/C_4 plant community persisted, with only slight increasing aridity over time. Through comparisons of δ^{13}C values from short-grass prairie modern soils and buried soils from archaeological contexts in western Texas, Oklahoma, and Kansas, the canyonlands offered a landscape with a more diverse plant

community and more effective moisture. This study has implications for comparing climate change data and plant community diversity across ecological boundaries, and for testing the relationships between paleoenvironmental data and archaeological and zooarchaeological data within the canyonlands.

Keywords: Southern Plains, soil, stable carbon isotopes, phytoliths, diatoms, historical ecology

1. Introduction

Mobile prehistoric hunter-gatherers of the North American Great Plains grasslands interacted with, altered, and adapted to local late-Quaternary climate fluctuations through their changes in behavior, subsistence, and technology. For example, on the Southern High Plains, people dug over 60 water wells to adapt to severe drought that caused declines in the water table during the middle-Holocene Altithermal (Meltzer, 1991). The magnitude of hunter-gatherer intervention and alteration of the landscape in grasslands can be subtle and difficult to detect because these small-scale economies had low population densities and more mobility compared to later sedentary groups. Yet, the interrelation between climate, human impacts on the landscape, and subsistence specialization "is indispensable to our understanding of the mechanisms of hunter-gatherer culture change" (Habu and Hall, 2013: 67). Both the "human ecology" approach (see Butzer, 1982) and the "historical ecology" approach (see Egan and Howell, 2001; Thompson, 2013) helps us view the paleoenvironmental record as part of a complex interrelationship between humans and the environment as opposed to environmental determinism or cultural ecology (c.f. Steward, 1955). Providing paleoenvironmental context for the archaeological record during the late Quaternary provides new opportunities to test the interrelationship.

Buried soils can be used to reconstruct late-Quaternary paleoenvironments in the Great

Plains of North America to provide context at archaeological sites (Reider, 1990; Mandel and Bettis, 2001; Murphy and Mandel, 2012; Mandel et al., 2014). Buried soils, or former stable land surfaces, contain paleoenvironmental information because they formed under certain bioclimatic conditions; these conditions are reflected in observable physical and chemical properties (e.g. soil structure, color, presence of carbonates). For example, organic matter and calcium carbonate content provide general information about past precipitation and temperature (Holliday, 1990; Mandel and Bettis, 2001). Previous studies from the Southern Plains have focused on broad climate trends inferred from soil data (e.g. Ferring, 1990; Hall, 1988, 1990; Boyd, 1997; Nordt et al., 2002, 2007; Holliday, 1995, 1997). However, these trends cannot reflect small-scale culturally significant responses to climate because slow rates and/or insufficient magnitude of change are not reflected in soil (Holliday, 1990). Soils also contain plant macrofossil (i.e. seeds, charcoal) and microfossil (i.e. phytoliths, diatoms) data that are useful in the Great Plains because of the ubiquity of buried soils in the absence of robust pollen and tree-ring data that are available in other regions (Zung, 2013; see Bement et al., 2007; Cordova et al., 2011). However, detailed information about specific, micro-paleoenvironments that reflect the context of small-scale hunter-gatherer economies is scant.

Research conducted through the Lubbock Lake Landmark and Museum of Texas Tech University aims at unraveling interaction between humans and grasslands while expanding the paleoenvironmental record in northwest Texas. The work includes ongoing interdisciplinary archaeological research on ~34,000 ha (~83,000 acres) of ranchland about 16 km southwest of Post, Texas, in the Texas Panhandle. The study area is within the "Escarpment Breaks" (Texas Parks & Wildlife, 2007) or "Caprock Canyonlands" (Boyd, 2004)—a physiographic boundary and ecotone between the flat Southern High Plains to the east and gentle Osage or "Rolling"

Plains to the west (hereafter referred to as canyonlands). According to Flores (1990: ix), the canyonlands provided a refuge for Native Americans from the "limitless expanse of the High Plains" because it contained "oases of water, trees, and wildlife." However, beyond these geographic observations, there is a need for detailed climate and environmental study as suggested by Quigg et al. (2010) within the canyonlands to understand microenvironments and how they served hunter-gatherer groups. To date, there is a heavy reliance on coarse data sets that show increasing aridity during the Holocene (i.e. Boyd, 1997, 2004), or that infer broad change from larger atmospheric circulation patterns from proxies outside of the Great Plains. Thus, under the premise that "climate reconstruction for any specific region must ultimately be assessed empirically, against data which derive directly from that region" (Bamforth, 1990: 360), we attempted to extract multiple proxies from soils and sediments to understand both the macro- and micro-paleoenvironments of the study area. The study area encompasses portions of the Southern High Plains, canyonlands, and western Rolling Plains (Figure 1). We pair soil and sediment description and radiocarbon chronology from Murphy et al. (2014) with stable carbon isotope values and microbotanical assemblages from buried soils and lacustrine sediments to reconstruct plant communities, the hydroclimate, and how they changed. We then compare our stable carbon isotope data with isotope data for other localities in the Great Plains to reconstruct the evolution of the short-grass prairie and the magnitude of changes during millennial-scale climatic events.

This study provides multiple-proxy paleoenvironmental results for the past ca. 20,000 years B.P. Many studies, including Greenland ice records (ICS, 2012), have focused on global perturbations in climate during the Pleistocene and Holocene, but few have focused on the small-scale changes that affect people at the local level. The eastern escarpment of the Southern Plains has undergone dramatic changes since the Last Glacial Maximum, but only a few studies in Texas have reported general climatic trends using stable isotope geochemistry of soil organic carbon (e.g., Holliday, 1995, Holliday 2000; Nordt et al. 2002; Holliday et al. 2008). Thus, obtaining a more thorough, high-resolution paleoenvironmental data set provides additional context for the geomorphic and archaeological record to compare to adjacent regions, and contributes to our understanding of past grassland dynamics and allows for more refined climate modeling.

2. Setting

2.1 Climate

The modern climate of the study area is continental and semi-arid. Summer droughts are common, and convective thunderstorms in the spring and summer (May-July) produce short episodes of heavy rain (Johnson, 2007) with 5-8 cm of rain each month (US Climate Data, 2014). For Post, Texas, mean annual precipitation is 55.8 cm (US Climate Data, 2014), but has historically ranged from less than 12.7 cm to over 101.6 cm from year to year (Wendorf and Hester, 1975). The average annual temperature is 17° C (62.7° F), with annual highs and lows of 24.6° C (76.4° F) and 9.4° C (49° F) (US Climate Data, 2014). Despite recent declines in groundwater levels, springs from the Ogallala aquifer still provide water year-round.

2.2 Vegetation

The modern plant community across the study area consists of a mix of short grasses, woody vegetation, and succulents. Blue grama (*Bouteloua gracilis*) and buffalo grass (*Buchlöe dactyloides*) dominate the C_4 short-grass prairie (Johnson, 2007; Wester, 2007). In addition, Dr. Craig Freeman, a botanist at the Kansas Biological Survey, identified modern plant samples from the study area, including purple threeawn (*Aristida purpurea*), silver beardgrass (*Bothriochloa* *laguroides* subsp. *torreyana*), alkali sacaton (*Sporobolus airoides*), hooded windmill grass (*Chloris cucullata*), and muhly (*Muhlenbergia sp.*). Woody vegetation such as honey mesquite (*Prosopis glandulosa*), Pinchot's juniper (*Juniperus pinchotii*), Netleaf hackberry (*Celtis reticulata*), and Berlandier's wolfberry (*Lycium berlandieri*) is common along edges of the escarpment and reentrant canyons. There are 14 species of native cacti and succulents common to the area, including soapweed yucca (*Yucca glauca*) and Twistpine pricklypear (*Opuntia macrorhiza*). Also, common sunflower (*Helianthus annus*) dots the landscape. This modern assemblage has likely been in place since the historic period, when cultivation, cattle grazing, desertification during droughts, and a reduced water table caused vegetation changes throughout west Texas, including most prominently, the spread of mesquite (Wester, 2007).

2.3 Soils

Surface soils across the Southern High Plains and Rolling Plains differ in color, texture, organic matter, and calcium carbonate content depending on parent material, landform, and landscape position. The Vernon-Rough broken land soil association, which occurs on scarps and hillslopes, dominates the canyonlands (Soil Survey Staff, 2010). Dissection of the landscape by intensive erosion in the canyonlands makes soils difficult to trace laterally. Nevertheless, there are five additional surface soils common in the study area: Mobeetie, Olton, Vernon, Portales, and Spur (Soil Survey Staff, 2010). All five soils have calcic horizons, and they are associated with either the Miocene-Pliocene Ogallala Formation or Plio-Pleistocene Blackwater Draw Formation lacustrine and eolian parent materials. Also, because of the soil types with the high calcium carbonate content, plant microfossils such as pollen and phytoliths, are not well preserved.

3. Paleoenvironmental Background

3.1 The Multiple-proxy approach

Stable carbon isotopes and plant microfossils provide complementary paleoenvironmental information that can be extracted from soils on the Great Plains. While stable carbon isotopes show climatic trends based largely on temperature, phytoliths provide more details about specific grass subfamilies. Diatoms, or microscopic algae abundant in certain soils and lacustrine sediments, hold information about water salinity and depth, and substrate and cover (Smol and Stoermer, 2010). A combination of carbon isotopes and microfossils more accurately reflects the former bioclimate and landscape, minimizing issues in interpretation that occur when only one proxy is used. Also, since lags occur between climate change and changes in terrestrial systems, such as groundwater levels and the composition of a plant community, a combination of proxies provides a better understanding of plant community response to climate change. Here, we use soil characterization and analysis, stable carbon isotopes, phytoliths, and diatoms to infer changes.

3.1.1 Stable carbon isotopes

We infer vegetation change and relative temperature from stable carbon isotope values of soil organic matter by comparing ratios of C_3 to C_4 photosynthetic pathways. C_3 and C_4 plants discriminate $^{13}CO_2$ during photosynthesis differently (Park and Epstein, 1960). The C_3 (rubisco) photosynthetic pathway occurs in all trees, most shrubs, and cool-season grasses, while the C_4 (dicarboxylic acid) photosynthetic pathway occurs in most drought-tolerant, warm season grasses (Boutton, 1996). The carbon isotope composition of soil organic matter reflects the contribution of the decomposed plant litter of C_3 or C_4 plants; there is little change in the $\delta^{13}C$ values between plant litter and soil organic matter (Dzurec et al., 1985; Nadelhoffer and Fry, 1988; Stout and Rafter, 1978, Melillo et al., 1989; Nadelhoffer and Fry, 1988). The composition of the plant community, particularly the proportion of C_4 biomass, reflects temperature (Boutton et al., 1980; Teeri and Stowe, 1976; Tieszen et al., 1979; Nordt et al., 2008). This is reflected in a study of $\delta^{13}C$ values from soils in modern prairies, where more southern latitudes have more carbon input from C_4 sources (Nordt et al., 2008; Figure 2). That is, as summer temperature increases, C_4 plant productivity increases (von Fischer et al., 2008), and as latitude decreases, C_4 plant productivity steadily increases (Tieszen et al., 1997) until the expansion of more drought-resistant grasses, woody vegetation and CAM plants around 33° N latitude (Nordt et al., 2008; Figure 2). These distinctions offer a way to compare modern grassland compositions to the past.

The $\delta^{13}C$ values, or the difference between the $^{13}C/^{12}C$ ratio and a known standard, are expressed in parts per mil (‰). C_3 and C_4 plants have distinct, non-overlapping $\delta^{13}C$ values and differ from each other by approximately 14‰ (Deines, 1980; Boutton, 1991b). Because of this discrimination, we can reconstruct past plant communities, track the changes in plant communities over time, and view the change in plant communities on the landscape as they respond to changes in temperature and climate. However, crassulacean acid metabolism (CAM), which is utilized by semi-arid and arid-climate plants such as succulents and cacti (Sharp, 2007), yield $\delta^{13}C$ values that are similar to values of a mixed C_3 and C_4 plant community. The carbon input of CAM plants into the soil complicate environmental interpretations in semi-arid study areas like those in northwest Texas.

3.1.2 Opal Phytoliths

Opal phytoliths, or "plant stones," are rigid, microscopic silica bodies deposited in cell walls, cell interiors, and intracellular spaces (Piperno, 2006). The C_3 or C_4 photosynthetic pathway distinguishes the major grass subfamilies; therefore, temperature and climate can be inferred from changes in relative abundance of each subfamily. Changes in relative abundance of C_3 and C_4 grass phytoliths can be quantified after extracting preserved phytoliths from soil sequences. Successful phytolith extraction and quantification from Great Plains buried soils reveal climatic shifts in the late Quaternary (Bement et al., 2009; Cordova et al., 2011). Thus, we can detect specific (i.e., subfamily-level) plant community response to climate change by quantifying specific changes in grassland composition, making phytoliths a powerful proxy because they allow a more accurate reconstruction of past landscapes.

The Poaceae family of grasses is divided into subfamilies based on phylogeny, which includes photosynthetic pathway and climatic regime; this makes paleoenvironmental reconstructions possible. The Chloridoideae (C_4), Panicoideae (mostly C_4), and Pooideae (C_3) subfamilies produce diagnostic phytoliths; that is, each subfamily produces their own phytolith shapes (Twiss et al., 1969; Brown, 1984; Fredlund and Tieszen, 1994). The Chloridoideae subfamily consists of C_4 short-grasses such as grama grass (*Bouteloua* spp.) and buffalo grass (*Buchloë dactyloides*). Most chloridoids are adapted to warm/dry climates, and have a diagnostic "saddle" short-cell phytolith. Panicoids are predominatly C_4 tall-grasses such as switchgrass (*Panicum*), indian grass (*Sorghastrum nutans*), big bluestem (*Andropogon gerardii*), and little bluestem (*Schizachyrium scoparium*) that are adapted to warm/moist climates. Panicoid morphotypes include cross-shapes and bilobates. Pooids are C_3 cool-season grasses that include bluegrass (*Poa* L.), wheatgrass (*Agropyron* spp), wild rye (*Elymus* spp), and needlegrass (*Hesperostipa* spp). Pooids produce a variety of unique morphotypes such as short cell, sinuate, and bilobate and polylobate trapeziforms. The differences in the phytolith shapes by subfamily allow for a more explicit, better inferred view of plant community compositions.

While grasses produce diagnostic phytoliths to the subfamily level, and in some cases the species level, most C_3 trees and shrubs do not. A few exceptions include herbaceous dicots and non-coniferous trees (i.e. Dicotyledonae class) native to the Great Plains that produce several general phytolith types. Dicots such as cottonwood (*Populus deltoides*) and white oak (*Quercus alba*) produce silicious polyhedral epidermal cells, branching trachedids, honeycomb assemblages, opaque perforated platelets, segmented hairs, and jigsaw puzzle piece shapes (Bozarth, 1992). Also, hackberry (*Celtis*) fruits produce diagnostic echinate phytoliths and the leaves produce verrucate cystolith phytoliths (Bozarth, 1992; Fredlund, 1998). Thus, C_3 trees and shrubs are less useful than grasses for quantifying specific plant community compositions, but their presence or absence provides additional information about paleoenvironments.

Stable carbon isotope values from soils offer a direct comparison to the recovered phytoliths, because changes in the relative proportions of C_3 vs. C_4 species inferred from the $\delta^{13}C$ values can be compared to the direct counts of C_3 and C_4 phytoliths. Comparisons between phytoliths and stable carbon isotopes reveal information about the input of carbon from C_3 trees and shrubs that are under-represented in the phytolith record (Fredlund and Tieszen, 1997; Piperno, 2006). Also, phytolith differentiation among the major grass subfamilies allows a more-refined assessment of stable carbon isotope data. Because warm/moist and warm/dry C_4 grasses can be differentiated based on phytolith morphotypes, paleoenvironmental assessments that are more precise than the broad trends recorded in stable carbon isotope values can be made. A more nuanced record is important for understanding microenvironments and smaller-scale changes, including seasonal changes that potentially impact hunter-gatherers.

Opal phytoliths are subject to a variety of site-dependent factors that affect their preservation in soils. For example, bioturbation, translocation, presence of iron and aluminum oxides, erosion, fire, wind, herbivory, anthropogenic activity, coarse soil texture, high (basic) soil pH, high deposition rates, and exposure to water are detrimental to phytolith perseveration

(Fredlund and Tieszen, 1997; Grave and Kealhofer, 1999; Piperno, 2006). Also, while grasses actively uptake soluble silica from the soil, other plants, such as C_3 trees, shrubs, and CAM plants do so passively and may produce phytoliths irregularly depending on local climate and soil conditions (Bozarth, 1992). Because of differential preservation and production issues, the full plant community picture is obscured when observed without additional lines of evidence. Thus, phytoliths should be compared with other paleoenvironmental proxies.

3.2 Multiple-proxy evidence for late-Quaternary paleoenvironments

Pollen records for the Southern High Plains point to a treeless *Artemisia* grassland during the LGM (Hall and Valastro, 1995). Evidence from both faunal assemblages (Graham, 1987) and soils indicate that the environment supported grasslands as opposed to forests (Holliday, 1987). In general, between ca. 20,000-11,000 ^{14}C yr B.P. (hereafter B.P.) the Southern Plains was a cool/temperate C_3 grassland that had less seasonality and more effective moisture than the modern short-grass prairie (Humphrey and Ferring, 1994; Fredlund et al., 1998; Holliday, 1995). Prior to the establishment of the modern C_4 prairie between ca. 11,000 and 8,000 B.P., cool-season (C_3) grasses such as *Hesperostipa*, *Nassella*, and *Piptochaetium* dominated west Texas (Wester, 2007). These C_3 grasses likely co-evolved with large herbivores sometime in the middle Miocene (~15 Ma) (Koch et al., 2004). However, pollen evidence is limited, and LGM plant communities of the Southern High Plains do not have a modern analog (Hall and Valastro, 1995).

The Pleistocene-Holocene transition (ca. 11,000-10,000 ^{14}C yr B.P.), or Younger Dryas Chronozone (YDC), featured, in general, a rapid return to cool and arid conditions after post-LGM warming, but the abrupt climate change discerned from Greenland ice cores was less pronounced in the North American midcontinent (Meltzer and Holliday, 2010). Soil stratigraphic records for the Great Plains indicate local environments drove geomorphic responses rather than one synchronous climate event (Haynes, 2008; Holliday et al., 2011). In other words, the YDC varied through time and space (Holliday et al., 2011). On the Southern Plains, stable carbon isotopes from soil organic matter indicate that a warm/semiarid C_4 grassland expanded with increasing summer temperatures (Holliday, 2000; Nordt et al., 2002; Nordt et al., 2008; Meltzer and Holliday, 2010). While the timing and mechanisms that triggered the decrease of C_3 plants and the spread of C_4 plants sometime in the Miocene are extensively debated (see Osborne and Beerling, 2006; Tipple and Pagani, 2007; Osborne, 2008; Edwards and Smith, 2010), reduced global atmospheric pCO_2 and increasing aridity likely drove local feedback mechanisms (e.g. increased seasonality and fire), favoring C_4 photosynthetic pathway expansion. Nevertheless, the short-grass prairie continued expansion during the YDC and was in place by ca. 9,000 B.P. (Cordova et al., 2011; Holliday et al., 2011).

For the Holocene (10,000 B.P.- present), multiple proxy paleoenvironmental data are often contradictory for the southern Plains concerning the timing and onset of more mesic and xeric periods. Some phytolith data from five Southern High Plains localities indicate a grama-buffalograss short grass prairie was in place by 10,000 B.P., while diatoms indicate regional wet and dry cycles, with prolonged drying between 8,000 and 6,500 B.P.; pollen data was inconclusive due to preservation issues (Holliday, 1995). The general trend from soil, pollen, and phytolith records (Balinsky, 1998; Fredlund et al., 1998, Ferring, 2001, Holliday, 2000; Mandel, 2008) indicates a general increase in aridity through the Holocene, with the most xeric conditions occurring during the middle-Holocene Altithermal (6,000-4,500 B.P.) (Holliday, 1989). For the late Holocene (4,500 B.P. to present), contradictory evidence for millennial-scale wet-dry cycles occurs from soils and stable carbon isotope data in Texas (Humphrey and Ferring, 1994;

Holliday, 1995; Lohse et al., 2014) and Oklahoma (Thurmond and Wyckoff, 1999; 2004). Other factors contribute to inter-regional and short-term variations in environmental changes during the Holocene, including local storm patterns (Holliday, 1995) and other local bioclimatic feedbacks, some of which occurred rapidly (Lohse et al., 2014). Thus, Holocene microenvironments, such as those in protected areas of the canyonlands, are important areas to elucidate local patterns and how they compare to larger climatic trends.

4. Methods

4.1 Field methods

Sections of late-Quaternary alluvium, colluvium, and lacustrine deposits exposed in cutbanks were described and sampled in Middle Creek, Spring Creek, and tributaries of South Fork (Figure 1). During the 2008 and 2009 summer field seasons, approximately 350 soil and sediment samples were collected from 17 localities (15 cutbanks and 2 localities drilled with a Giddings® hydraulic soil probe) to ascertain late-Quaternary landscape evolution (see Murphy et al., 2014). Selected samples were used for stable carbon isotope and plant microfossil analysis. Soil profiles were described following standard USDA procedures (Soil Survey Staff, 2010), and samples were collected at 5 cm intervals. Stratigraphic units labeled with roman numerals are informal. Buried soils are numbered consecutively after the "b" (Holliday, 2004). Radiocarbon ages determined on soil organic matter are reported in uncalibrated years B.P. in the text, and in calibrated years B.P. in Table 1. Radiocarbon ages were calibrated using OxCal 4.2.3 (Bronk Ramsey, 2009) and the IntCal 13 curve (Reimer et al., 2013). A detailed summary of the radiocarbon chronology for the study area is presented in Murphy et al. (2014). Also, twelve modern plants collected across the study area were identified, and then processed to extract phytoliths to create a modern reference collection for the study area.

4.2 Stable carbon isotopes and %C

Stable carbon isotope values and total organic carbon content (C) of the soil were determined on a mass spectrometer to obtain the signature of C_3 vs. C_4 photosynthetic pathways preserved in the organic carbon. The analyses were conducted at the Keck Paleoenvironmental and Environmental Stable Isotope Laboratory (KPESIL), University of Kansas. Raw $\delta^{13}C$ values are obtained via high-temperature combustion with a Costech ECS4010 elemental combustion system in conjunction with a ThermoFinnigan MAT253 isotope ratio mass spectrometer. International standards of known $\delta^{13}C$ values are used to calibrate unknown soil $\delta^{13}C$ values. A precalibrated internal standard (DORM-2 dogfish muscle; National Research Council of Canada) is used in the $\delta^{13}C$ calibration curve, as well as for %C determination. The precision of reported $\delta^{13}C$ values is based on a linear correction of observed values versus expected values of the standards; typical standard calibration curves yield an R^2 of 0.9994 or greater.

3.2.1 Calculation of C_4 productivity

C_4 grass productivity on past landscapes compared to the modern short-grass prairie is found by calculating the difference between the $\delta^{13}C$ values of modern prairie soils and the $\delta^{13}C$ values from buried soils. Relative C_4 plant productivity was calculated using $\delta^{13}C$ values from buried soils in the study area compared to -14.7‰, the modern Texas soil value formed under short-grass prairie reported by Nordt et al. (2008) that was derived from near the same latitude and longitude (~33°N 101°W) as the canyonlands study area. The difference between the two values ($\delta^{13}C_{buried}$ and $\delta^{13}C_{modern}$), or standard delta (expressed as $\Delta\delta^{13}C$), was plotted with associated radiocarbon ages determined on soil organic matter (Murphy et al., 2014) and compared to the C_4 plant productivities for the Southern High Plains reported by Holliday (1995) and used by Nordt et al. (2008) (Table 1) to discern similarities or differences across the landscape. More positive $\Delta\delta^{13}C$ values indicate C_4 plants contributed more carbon to the soil organic pool than today, whereas more negative $\Delta\delta^{13}C$ values indicate C_4 plants contributed less to the soil organic pool than today.

4.3 Phytoliths and Diatoms

Phytoliths were extracted from modern grass samples at the Kansas Geological Survey for a reference collection. Grass inflorescences were separated into crucibles, oven-dried at 105°C overnight, and then burned in a muffle furnace at 550°C for two hours. A small amount of 0.5 N HCl was added to each crucible, and then the ashed samples were transferred to 15 mL centrifuge tubes, and rinsed and centrifuged twice with deionized water. Phytoliths were transferred to a microscope slide using a pipette. Slides were dried on a hot plate before mounting in standard Type A immersion oil.

For microfossils preserved in soil and sediment, samples were pretreated based on the procedure developed by Piperno (1988, 2006) and Pearsall (2000). Biogenic silica was extracted using a non-toxic heavy liquid flotation (HLFPol) method described in Lentfer and Boyd (1998). The HLFPol method calls for potassium hydroxide to remove humic acids while preserving pollen and charcoal. A heavy liquid solution of 2.30-2.35 g/mol sodium polytungstate separates biogenic silica from soil/sediment. Ten samples were sent to J.S. Enterprises, Inc. of Ponca City, Oklahoma, for phytolith extraction by Dr. J. Byron Sudbury to address specific problems with phytolith recovery due to high soil pH, low silt content, and low phytolith concentrations due to the depositional environment and/or antiquity of the soils or sediments. Phytolith procedures were modified by Sudbury to address the difficult samples, and a 2.38 g/cm^3 zinc bromide solution was used to float biogenic silica. Microfossil isolates were mounted on slides in both immersion oil to allow for three-dimensional rotation and Canada balsam. Short-cell phytoliths and diatoms were counted with a standard microscope at 40x objective along non-overlapping transects until at least 200 short cell phytoliths were counted in concordance with statistical methods (see Piperno, 2006). Short-cell grass phytoliths were normalized to 100%. Images were taken at 500x magnification with an Olympus Infinity 2 camera. Diatoms recovered from one locality at PLK-73 Profile A were counted to 500 and identified by Dr. Barbara Winsborough at the Texas Memorial Museum, University of Texas.

5. Results

5.1 Modern plant community phytoliths

Successful phytolith extractions from modern plant specimens include short-cell morphotypes from each of the C_4 grasses. Purple threeawn (*Aristida purpurea*) produced long-shank bilobates typical of aristida in both the seed and sheath (Figure 3A). Muhly (*Muhlenbergia sp.*), hooded windmill grass (*Chloris cucullata*), and alkali sacaton (*Sporobolus airoides*) produced saddle-shaped phytoliths (Figure 3B, 3C). Silver beardgrass (*Bothriochloa laguroides* subsp. *torreyana*) produced several cross and bilobate shapes (c.f. Sudbury, 2011). Pinchot's juniper (*Juniperus pinchotii*) also produced globular echinate (spinulose sphere) phytoliths (c.f. Morris et al., 2009; Sudbury, 2011).

5.2 Middle Creek

In the upper reaches of Middle Creek at PLK locality 73 (Profile A), buried soils in lacustrine and colluvial deposits yielded $\delta^{13}C$ values typical of a mixed C_3/C_4 plant community (Figure 4). The most negative values within the YD-aged soil indicate cooler and/or more mesic conditions compared to the early to middle Holocene. The values range between -21.08‰ in the 3Bkb3 horizon and -17.82‰ in the Bk horizon near the modern surface, representing a minimal ~3‰ shift. All of the $\delta^{13}C$ values fall within a mixed plant community. Carbon content increases at the top of each buried A-horizon, with an additional spike in %C in the middle of the 3Bkb3 horizon from the organic-rich lacustrine sediments (Figure 4).

A well-preserved phytolith assemblage was recovered from buried soils at PLK-73A (Figure 4), with the exception of the first buried soil. The Akb1 horizon had a low phytolith yield (34 short cells), 65% of which were cool/moist pooids, and 15% were warm/dry chloridoids. The 2Akb2 horizon developed in colluvium that aggraded between ca. 8500 and 8900 B.P. In the upper 5 cm of this horizon (70-75 cm), 73% of the short cells are pooids, 17% are chloridoids, and 5% are warm/moist panicoids; an additional 5% are drought-resistant stipa-type pooids. The sample from the middle of the 2Akb2 horizon (85-90 cm) contains 60% pooids, 34% chloridoids, and 6% panicoids. The 3Cb3 horizon at the bottom of the profile is older than ~10,260 B.P. and contains 79% pooids, 3% panicoids, and 18% chloridoids. Thus, from the bottom to the top, the phytolith data corroborate the slight overall drying trend inferred from the $\delta^{13}C$ data, pointing to a cool/moist environment at the terminal Pleistocene with some warming and drying as indicated by the increase in chloridoids to 34% in the 2Akb2 horizon. However, there are more subtle changes in the phytolith assemblage than the isotope record – particularly, the increase in panicoids (15%) in the bottom of the 2Ak2b horizon, indicating increased temperatures but more effective moisture at ca. 8525 B.P. The other four samples between 125 and 145 cm in the third buried soil have a fairly consistent grass phytolith assemblage, with 72-84% pooids, 13-21% chloridoids, and 3-5% panicoids, suggesting again, that there was not a dramatic turnover in the plant community over time.

As an additional line of evidence, 74 diatom taxa were identified from five PLK-73A soil samples. The five most abundant taxa are presented in Figure 5. Three paleonvironmental "zones" were interpreted based on the changes in the diatom assemblage. Zone 1, the lowermost zone, consists of three samples within the 3Bkb3 and 3Cb3 lacustrine soil. *Diadesmis gallica* (formerly *Navicula gallica*) represents almost half of the population in all three samples. *D. gallica* thrives under cool, very low light conditions with intermittently damp moss, rock, and sediment, and is often reported from caves and crevices (e.g., St. Clair et al., 1981), but it has also been reported from three lacustrine deposit localities on the Southern High Plains (Holliday, 1995). Zone 2, within the 3Akb3 horizon, contains a marked increase in *Denticula elegans*, *Rhopalodia rupestris*, and *R. gibba*, indicating warming conditions with carbonate-rich hard or brackish water typical of a marsh or shallow lake that dried seasonally (Figure 6). Also, *Epithemia argus* (Figure 6), one of the most common species in late-Quaternary lacustrine sediments on the Southern High Plains (Lintz et al., 1993; Holliday, 1995), is most abundant in Zone 2 compared to all other species counted in the other 4 samples. In Zone 3, within the 2Akb2 horizon, *Luticola mutica* dominates with other aerial diatoms associated with mud, moss, or damp soil, also indicating seasonally drying of a shallow lake or marsh.

5.3 Spring Creek

At upper Spring Creek near the Southern High Plains surface (Macy locality 31), a transect of four cores and one cut-bank profile revealed laterally inset alluvial and palustrine fills spanning the period ca. 22,000-3000 B.P. (see: Murphy et al., 2014; Figure 7). Stable carbon isotope values were determined from cores 1 and 4 (Figure 7). The core 4 isotope trend shows a C_3 community through several lacustrine units at depth, around the time of the LGM. This is followed by a trend of increasing aridity, where a mixed C_3/C_4 plant community persisted until the lacustrine deposits were buried by a now stabilized eolian sandsheet that exhibits $\delta^{13}C$ values typical of C_4 grasses. The lowest $\delta^{13}C$ value, -26.1‰, occurs at the base of the first lacustrine unit 655 cm below surface, and the highest value, -14.48‰, occurs in the A horizon of the eolian unit, 30-35 cm below surface; this is an offset of ~11.62‰, suggesting a dramatic turnover in the plant community from the LGM to the present. The C data show consistent carbon contents of less than 1% through the profile with a few exceptions, such as the spike in Unit VIII. Minor increases in C content are attributed to the presence of organic-rich lacustrine strata.

Downslope from core 4 and near the Spring Creek cutbank, stable carbon isotope data from core 1 show a mixed C_3/C_4 signal for approximately the past 9820 years B.P., with more contributions from C_4 plants toward the top of the profile in the modern soil (Figure 7). The highest C content occurs in the A horizons of the surface soil and in the ABtk horizons of the buried soils.

Plant microfossils were recovered from four sediment samples in the LGM-age lacustrine units in core 4 (Figure 8), and mammoth tarsals were eroding from a road cut associated with these units. These sediments contained 83-94% pooids, 4-7% chloridoids, and 0-9% panicoids. Short-cell yields were low compared to larger silica bodies likely produced by trees and bulliform cells, many of which exhibited partial dissolution (Figure 9). In core 1, the buried soil (ABtkb1) dating to ca. 4700 B.P. contained 64% pooids, 34% chloridoids, and 1% panicoids. Thus, there were two to three times more C_4 grasses in the middle-Holocene soil than in the LGM-aged lacustrine sediments at the same locality.

Downstream from Macy 31, a core at Macy locality 3 in middle Spring Creek displayed ~6 m of relatively thin, organic-rich palustrine deposits bounded by alluvium (Figure 10). Based on the stable carbon isotope data, a mostly mixed C_3/C_4 plant community was in place during the Holocene. However, the composition of the community changed rapidly during the period of record, especially between ca. 10,170 and 5135 B.P. The rapid shifts are likely due to wet and dry cycles, with more organic carbon incorporated in the sediment during wet episodes. At the top of the core, C_4 grasses strongly influence the plant community. The C data rapidly shifts back and forth, which represents the changes in organic carbon content between palustrine deposits rather than pedogenic processes. Microfossil yields for four of the most organic-rich samples in the core were too low to be considered statistically valid.

5.4 South Fork

Within small tributaries along South Fork, localities at Macy 5, 44, and 48 exhibit late Holocene pedocomplexes developed in alluvium (Figure 11) (Murphy et al., 2014). Stable carbon isotopes indicate that a mixed C_3/C_4 plant community persisted for the last 1500-2000 years B.P. without much change at Macy 5 and Macy 48. At Macy 44, which was interpreted as a late Holocene cut and fill sequence with a truncated buried soil (Murphy et al., 2014), isotope values are less stable and show change from a more dynamic fluvial setting, although the values generally stay within the mixed plant community range. The C content reflects pedogensis, with increases in C within buried soils (Figure 11).

Plant microfossils were difficult to extract from late Holocene soils due to high carbonate and low silt content, but four samples from rapidly buried soils with the highest silt percentages in the profiles had well-preserved diagnostic short cells, particularly in the better persevered deeply buried soils at Macy 5. At Macy 5, chloridoids dominated in the top the first buried soil (4ABtb1) (Figure 12). Samples within the 4ABtb2 and 4ABtb3 horizons were dominated by pooids around 1505 B.P. At Macy 48, chloridoids and pooid percentages were about even around 785 B.P., reflecting the mixed plant community indicated by stable carbon isotope values (Figure 12).

5.5 C_4 productivity

The results for C_4 productivity, or the difference between the $\delta^{13}C$ value of the modern short-grass prairie and the $\delta^{13}C$ values for buried soils in the study area, are expressed as $\Delta\delta^{13}C$ and are presented in Table 1. The standard delta values range between -2.18 and -5.96‰. The more negative $\Delta\delta^{13}C$ values are associated with late Pleistocene and early Holocene soils, and thus these soils had the least C_4 plant contributions to the soil organic carbon pool. Late Holocene soil $\Delta\delta^{13}C$ values range between -3.14 and -3.75‰. One middle Holocene soil, with a -2.18 $\Delta\delta^{13}C$ value, reflects the most C_4 productivity of the buried soils tested within the study area. Compared to buried soils in draws throughout the Southern High Plains to the west, the canyonlands study area soils exhibited less C_4 productivity throughout the Holocene (Figure 13). This is especially evident when comparing late Holocene soils, where a stronger influence of C_3 plants persists in the canyonlands compared to the Southern High Plains. In other words, during the past 4,000 years B.P., the canyonlands likely had greater plant community diversity supported by more effective moisture.

6. Discussion

Results indicate that microenvironments, or small, specific areas distinguished from their surroundings by other variables such as moisture content, sunlight exposure, slope, etc., paint a diverse and more nuanced picture of the study area, and contribute to understanding the canyonlands and its potential resources for hunter-gatherers compared to adjacent landscapes. These microenvironments occur in different landscape positions and contributed to the variability in phytolith preservation. For example, the upper reaches of Middle Creek were favorable for phyolith and diatom preservation despite the calcic soils, likely because of a higher percentage of the silt fraction containing the microfossils, as well as depositional environment. Moreover, the upper reaches of Middle Creek have been less impacted by erosion than other landscape positions in the study area – the draw at PLK 73 is only now being eroded and exposed.

The longest core (Macy locality 31, core 4) with the oldest sediments dating to the LGM, produced stable carbon isotopes values indicating C_4 productivity increased during the LGM, with a general trend toward increasing C_4 productivity through the Pleistocene and Holocene (Figure 7). Many unidentified silica bodies, similar to phytolith production in trees point to a significant contribution of trees on the landscape prior to the LGM. At several localities in both Spring and Middle Creeks, the Pleistocene-Holocene transition and early Holocene contain palustrine and lacustrine deposits that varied in thickness, carbon isotope values, and phytolith and diatom recovery, but the data point to frequent wet-dry cycles but an overall high effective moisture. While proxy data from late Holocene soils show increasing aridity, C_3 plants still made contributions to the soil carbon and phytolith assemblages more so than on the Southern High Plains.

When comparing only the $\delta^{13}C$ record from this study's buried soils to the Kanorado locality in western Kansas (Cordova et al., 2011), Bull Creek in Oklahoma (Carter et al., 2009), and the Richard Beene site in south-central Texas (Nordt et al., 2002), patterns emerge (Figure 14). There is a general increase in overall C_4 productivity during the YD, followed by a continual and gradual increase of aridity and C_4 productivity through the Holocene. Increasing aridity, however, is much more muted in the study area as evidenced by $\delta^{13}C$ values from soil profiles (Figure 14) and the C_4 productivity results compared to the Southern High Plains (Figure 13). This is because the eastern escarpment of the Southern High Plains likely offered protected areas near Ogallala aquifer springs that supported more diverse vegetation. Further work is needed to compare the canyonlands to the Rolling Plains to the east, in order to call label the canyonlands a true "ecotone" as claimed by Flores (1990).

6.1 C_4 productivity

For the past 12,000 B.P., the $\Delta\delta^{13}C$ values for the study area indicate that the contribution of C_4 productivity remained below levels typical for modern Texas short grass prairies, including during the late Holocene. This is not always the case based on $\Delta\delta^{13}C$ for the same latitude and longitude in the Southern High Plains (Figure 13). Thus, C_4 productivity depends largely on local environment rather than global atmospheric mechanisms, including moisture availability, as well as other local microenvironment factors and geomorphic context. However, it still remains unclear how much input CAM succulents and cacti have contributed to late-Holocene buried soils in the study area, and therefore, how much CAM plants effected the calculations of C_4 productivity.

6.2 Issues in Biogenic silica extraction

Given the nature of the dissected landscape of the study area, which lacks lateral continuity of soils, and the semi-arid environment that promotes the production of pedogenic carbonate, the recovery of microfossils remains problematic and limited despite improvement in extraction procedures. Excessive calcium carbonate inhibits preservation of biogenic silica, which goes into solution around pH 8.2. However, through this study, we found that biogenic particulate recovery is possible from carbonate-enriched soil, but it is tedious, laborious, and very time consuming. The real possibility of biogenic particle dissolution does exist, and can be partial. A case in point is the surface damage and partial particle loss due to chemical dissolution on large bulliform cells from Macy 31 (Figure 9B). It is also possible that some phytolith assemblages may be incomplete due to selective particle dissolution (where smaller particles preferentially dissolve – i.e., those phytoliths having a high surface area relative to low particle volume), or possibly total biogenic dissolution, which apparently occurred in short-grass prairie soils in Oklahoma below a depth of 25 cm (Sudbury 2011: 112). Adding an additional proxy, such as plant materials recovered from floatation (will strengthen our understanding of vegetation used by hunter-gatherers in conjunction with wood charcoal identification from hearth features (see Quigg, 2010: 40-41).

6.3 Archaeological Implications

Millennial-scale climate change based on global climate records (i.e. Greenland ice cores) can make it difficult to understand the impact of local, shorter-scale, and microenvironment changes and the impact on hunter-gatherer subsistence strategies. Meltzer and Holliday (2010) argue that large-scale climate perturbations such as the Younger Dryas Chronozone (YDC) require directly tying local changes in the biotic communities to changes in the archaeological record in order to understand the impact on hunter-gatherer economies. This is particularly true for the Southern Plains where an event like the YDC may have not been as dramatic as recorded in Greenland. Nevertheless, a comparison of the $\delta^{13}C$ trends for the past 12,000 B.P. from five archaeological contexts, including this study (Figure 14), show increasing C_4 productivity during the YDC, which is also corroborated by isotope data determined on snails from the Folsom site in New Mexico (Balakrishnan et al., 2005). These millennial scale climate data gleaned from archaeological sites has implications for understanding broad cultural and technological changes in the archaeological record.

Based on the results of this study, the canyonlands had more effective moisture and supported a more diverse plant community during the Holocene compared to the adjacent Southern High Plains (Meltzer, 1991, Holliday, 1995). Although the composition of grasses and woody vegetation changed from locality to locality based on microenvironment, there is no evidence that a C_4 short-grass prairie of modern composition ever dominated in this area. This has implications for the development of niche-based (Laland and O'Brien, 2004) and optimal foraging (Winterhalder and Smith, 1981) models for the canyonlands versus the Southern High Plains and Rolling Plains when coupled with archaeological and zooarchaeological data. For example, recent stable carbon and nitrogen analyses determined on bison bones from mid-late Holocene archaeological sites western and south-central Texas shows bison populations increased during mid-late Holocene century-scale wetter intervals, which correspond to human adaptive responses (Lohse et al., 2014).

Despite a paleoenvironment signal problem due to poor phytolith preservation in some soils, the study area was not a treeless plain, and it likely provided protection from the winds on the Southern High Plains surface and offered resources for constructing hearth features for heat and cooking (Hurst et al., 2008). To date, 385 fire-cracked rock features have been documented in the study area. It is likely that available resources, such as fuel and abundance of raw Ogallala material for lining hearth features (see Hurst et al., 2008), influenced human use and hearth construction in the study area. We can now compare the hearth structure and function change over time to the changes in Holocene climate within the study area and compare results of hearth and paleoclimate data to the larger southern Plains region.

7. Conclusions

The prevailing "tool-kit approach" that geoarchaeologist's use to answer larger questions about context in archaeology remains important in order to gather paleoenvironmental evidence across landforms of different ages and to tie the evidence directly to archaeological deposits from the same region. However, because the study area is strongly affected by erosion, it is not an ideal place to find consistently preserved stratigraphic deposits for chemical or microfossil paleoenvironmental analyses. This is because erosion at the steep Caprock escarpment edge, including alluvial and coalluvial processes that have reworked soils and sediments, as well as eolian processes, impact primary contexts. The semi-arid environment is not ideal for the preservation of plant microfossils in the form of biogenic silica. Furthermore, there is no modern analog that would reflect the canyonlands environment at the terminal Pleistocene, making it difficult to identify the biogenic silica recovered from soil of that age. Future work calls for continued refinement of the methods for microfossil extraction from semi-arid areas with typically low yields, as well as better identifying unknown cells of biogenic silica. Nevertheless, this study has gleaned smaller-scale climate variations and microenvironments that can now be used to form models and test hypotheses with the cultural material being recorded and dated in the study area.

Despite some preservation issues, the multiple proxy data presented here support the eastern “Escarpment Breaks” or “Caprock Canyonlands” as a transitional ecological boundary, with a plant community different from the Southern High Plains. The overall climate trend from the Pleistocene through the Holocene shows gradual increasing aridity, including increases in C_4 plant productivity over the past ~20,000 years. In general, from profile to profile of different age and in different geomorphic settings, stable carbon isotopes in conjunction with soil properties, phytoliths, and diatoms indicate that a mixed C_3/C_4 plant community persisted throughout the Holocene, and shallow lakes and springs were subject to seasonally wetting and drying. There may be an unknown influence of CAM plants contributing carbon to the soil, but CAM plant population comprises a small portion of the plant community on the landscape. Paleoenvironmental proxy preservation was better in certain areas that were geomorphically more stable than others; that is, where soils or lacustrine sediments were rapidly buried and minimally affected by post-depositional alteration.

While global and millennial-scale climate models and proxy data have helped us understand patterns of prolonged cold and/or aridity, and the temperature-dependent spread of the C_4 photosynthetic pathway in the Great Plains, it is the short-term and microenvironment variations that will better inform us about regional human behavior across ecological boundaries. We are beginning to understand that the both the YDC and mid-Holocene Altithermal had short-term climate variations during what have been otherwise characterized as "abrupt," "prolonged," or "uniform" evens from global, millennial-scale models. Finally, because the southern Plains are tied to research about mobile hunter-gatherers who hunted top-ranked resources such as *Bison bison* (Lohse et al., 2014), multiple proxy paleoenvironmental data helps us identify the potential magnitude of connection between temperature, effective moisture, fauna populations, as well as human populations and their cultural remains.

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Table 1. Stable carbon isotope data from radiocarbon dated buried soils (humates) in the study area compared to stable carbon isotope values of the modern short-grass prairie, and buried soils from the Southern High Plains of Texas (Holliday, 1995) and used in Nordt et al. (2008).

Locality Name	Uncalibrated ^{14}C yr BP	±	Calibrated ^{14}C yr BP*	Buried $\delta^{13}C$	Modern $\delta^{13}C$	$\Delta\delta^{13}C$	Environment	State	Lat	Long	Source
Macy 48	785	80/75	788-668	-17.8	-14.7	-3.14	Fluvial	TX	33	101.3	Murphy et al., 2014
Macy 48	1170	125/120	1236-965	-17.8	-14.7	-3.14	Fluvial	TX	33	101.3	Murphy et al., 2014
Macy 48	1335	105/100	1354-1096	-18.3	-14.7	-3.56	Fluvial	TX	33	101.3	Murphy et al., 2014
Macy 5	1350	120/115	1388-1095	-18.4	-14.7	-3.75	Fluvial	TX	33	101.3	Murphy et al., 2014
Macy 31, Profile A	3015	135	3364-3007	-18.2	-14.7	-3.49	Fluvial	TX	33	101.3	Murphy et al., 2014
Macy 31, Core 1	4745	40	5583-5334	-16.9	-14.7	-2.18	Fluvial	TX	33	101.3	Murphy et al., 2014
Macy 20	7405	50	8310-8180	-19.0	-14.7	-4.34	Co-alluvial	TX	33	101.3	Murphy et al., 2014
Macy 31, Core 1	8155	40	9129-9021	-19.3	-14.7	-4.56	Fluvial	TX	33	101.3	Murphy et al., 2014
PLK 73, Profile A	8525	225/220	9888-9267	-19.1	-14.7	-4.43	Fluvial	TX	33	101.3	Murphy et al., 2014
PLK 73, Profile A	8935	120	10,230-9889	-19.6	-14.7	-4.87	Fluvial	TX	33	101.3	Murphy et al., 2014
Macy 31, Core 1	9820	45	11,249-11,203	-18.9	-14.7	-4.21	Fluvial	TX	33	101.3	Murphy et al., 2014
PLK 73, Profile A	10,260	315/305	12,522-11,412	-20.7	-14.7	-5.96	Lacustrine	TX	33	101.3	Murphy et al., 2014
Lubbock Lake	8730	230	10,147-9537	-18.0	-14.7	-3.3	Fluvial	TX	34	101.8	Holliday 1995
Yellowhouse Draw	8590	80	9656-9494	-16.0	-14.7	-1.3	Fuvial	TX	34	102.7	Holliday 1995
Lubbock Lake	8400	70	9496-9311	-18.8	-14.7	-4.1	Fluvial	TX	34	101.8	Holliday 1995
Lubbock Lake	7840	70	8761-8543	-14.8	-14.7	-0.1	Fluvial	TX	34	101.8	Holliday 1995
Blackwater Draw	7340	180	8340-8006	-21.1	-14.7	-5.8	Fluvial	TX	34	103.1	Holliday 1995
Mustang Springs	6680	40	7586-7510	-16.1	-14.8	-1.3	Fluvial	TX	32	101.8	Holliday 1995
Mustang Springs	6600	35	7559-7444	-16.3	-14.8	-1.5	Fluvial	TX	32	101.8	Holliday 1995
Plainview	3880	60	4412-4241	-16	-14.7	-1.3	Fluvial	TX	34	101.7	Holliday 1995
Lubbock Landfill	3140	100	3459-3215	-15.6	-14.7	-0.9	Fluvial	TX	34	101.8	Holliday 1995
Sulpher Draw	2610	50	2786-2711	-14.2	-14.7	0.5	Fluvial	TX	34	102.6	Holliday 1995
Plainview	2070**	130	2300-1885	-15.5	-14.7	-0.8	Fluvial	TX	34	101.7	Holliday 1995
Lubbock Lake	2070**	130	2300-1885	-15.7	-14.7	-1	Fluvial	TX	34	101.8	Holliday 1995
Lubbock Lake	1590**	40	1531-1415	-16	-14.7	-1.3	Fluvial	TX	34	101.8	Holliday 1995
Lubbock Lake	1590**	90	1567-1379	-15	-14.7	-0.3	Fluvial	TX	34	101.8	Holliday 1995
Lubbock Lake	1570**	70	1536-1392	-15.2	-14.7	-0.5	Fluvial	TX	34	101.8	Holliday 1995
Lubbock Lake	1550**	50	1522-1393	-15.5	-14.7	-0.8	Fluvial	TX	34	101.8	Holliday 1995
Lubbock Lake	1350**	40	1307-1190	-15.6	-14.7	-0.9	Fluvial	TX	34	101.8	Holliday 1995
Lubbock Lake	1270**	40	1268-1181	-14	-14.7	0.7	Fluvial	TX	34	101.8	Holliday 1995

*Calibration to calendar years at 1 sigma (68.2% probability) was performed with OxCal v4.2.3 (Bronk Ramsey, 2013) using calibration dataset IntCal 13 (Reimer et al., 2013).

**The age is corrected from its appearance in Table 1 of Nordt et al., 2008.

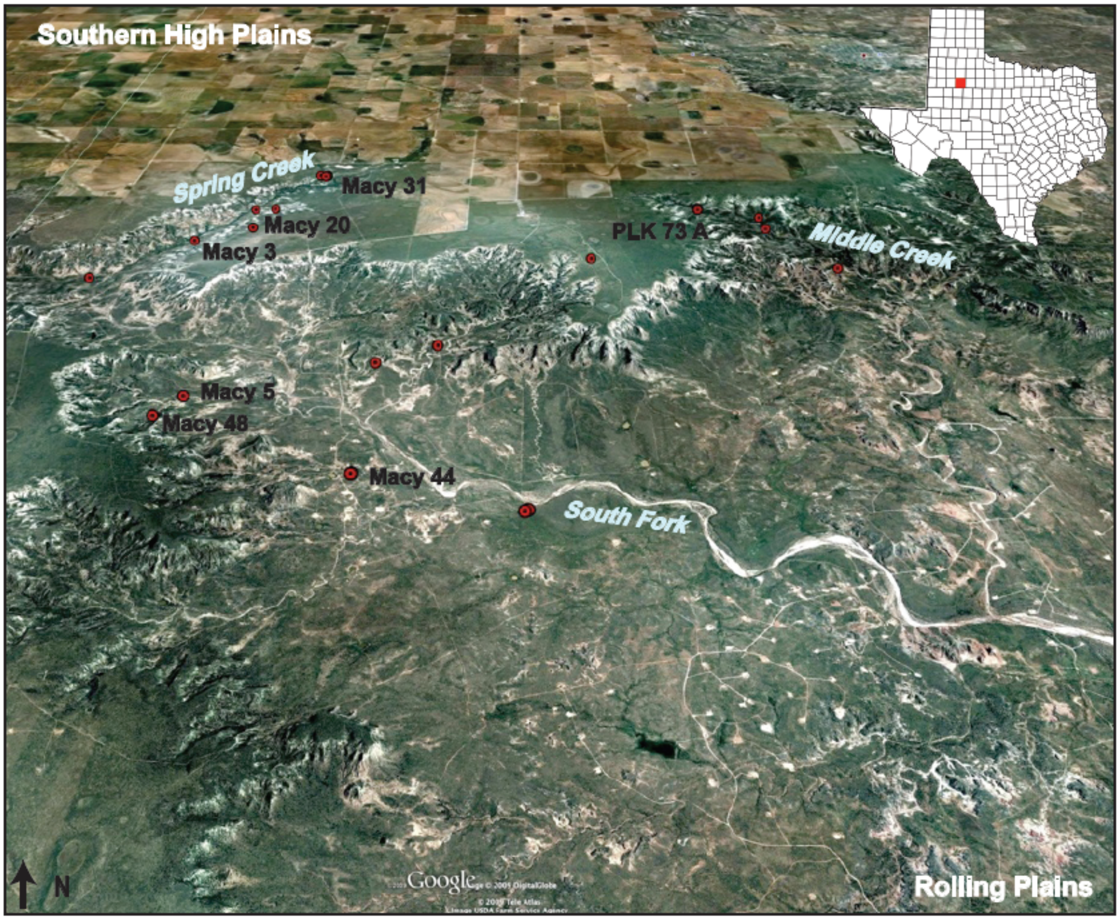

Figure 1. Google Earth image of the study area in Garza County, Texas, showing the flat Southern High Plains surface to the northwest and Rolling Plains to the southeast. Dots are localities described and sampled (Murphy et al., 2014). Labeled localities are discussed in the text.

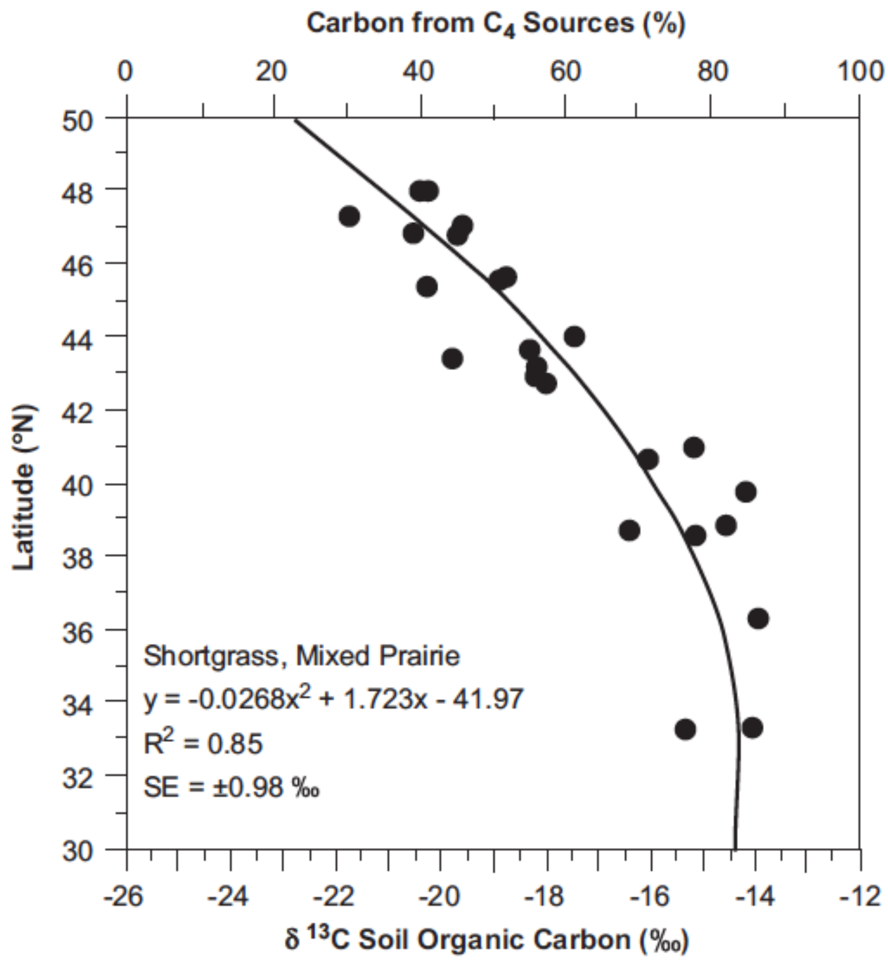

Fig. 2. The $\delta^{13}C$ values and estimates of relative C_4 production of modern prairie soil organic carbon versus latitude for mixed and shortgrass prairie of the Great Plains study area. The soil organic $\delta^{13}C$ data are regressed against latitude, with the former as the dependent variable (SE = standard error). For visual purposes the $\delta^{13}C$ data are plotted as the *x*-axis and latitude as the *y*-axis.

Figure 2. The relative C_4 production of from modern prairie soil organic carbon compared to latitude, from Figure 2, Nordt et al. (2008).

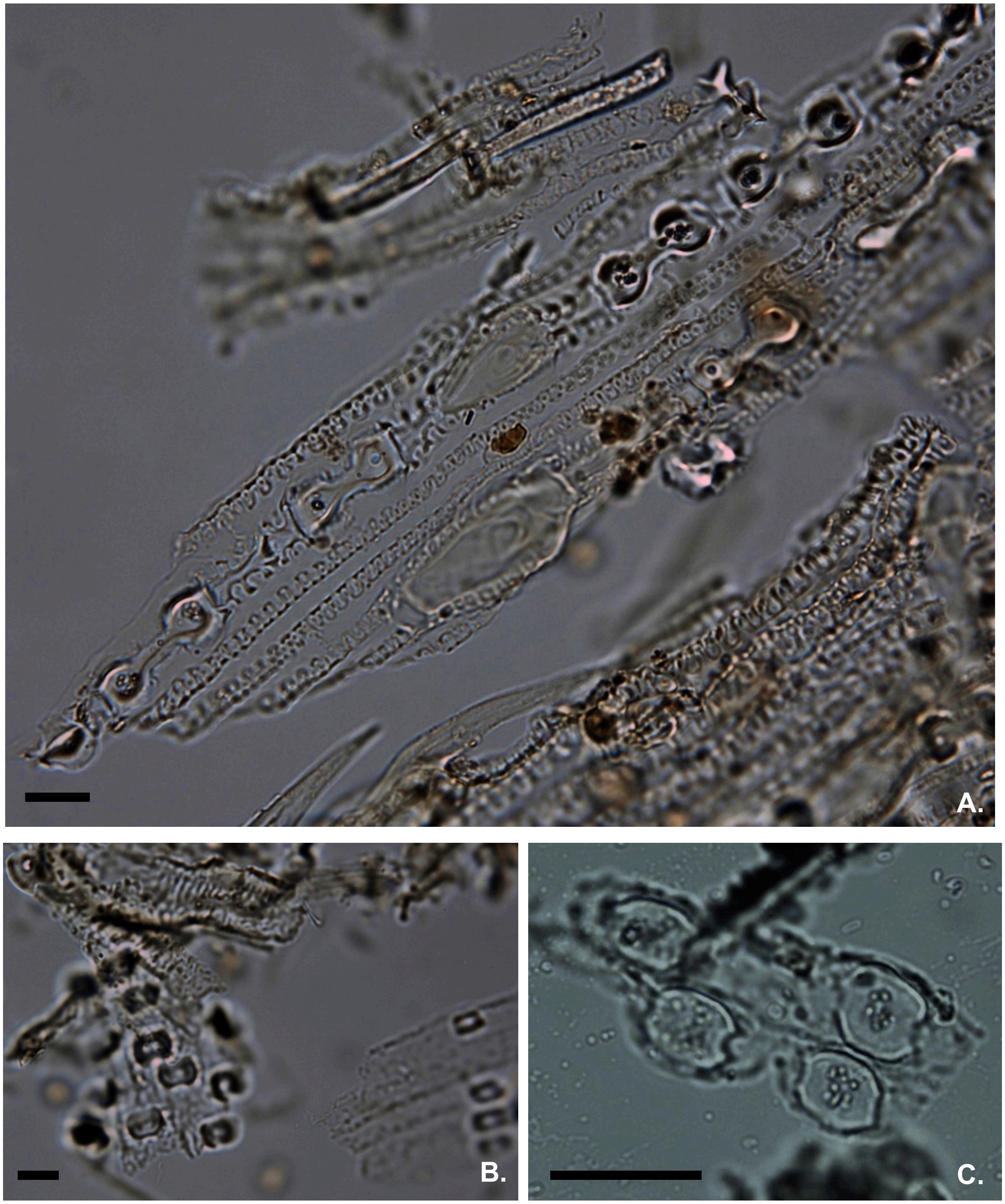

Figure 3. Phytoliths recovered from modern plant specimens collected from the study area. Scale bar: 20 microns. A. Purple threeawn (*Aristida purpurea*) long-shank bilobate phytoliths. B. Muhly (*Muhlenbergia sp.*) short cells. C. Hooded windmill grass (*Chloris cucullata*) short cells.

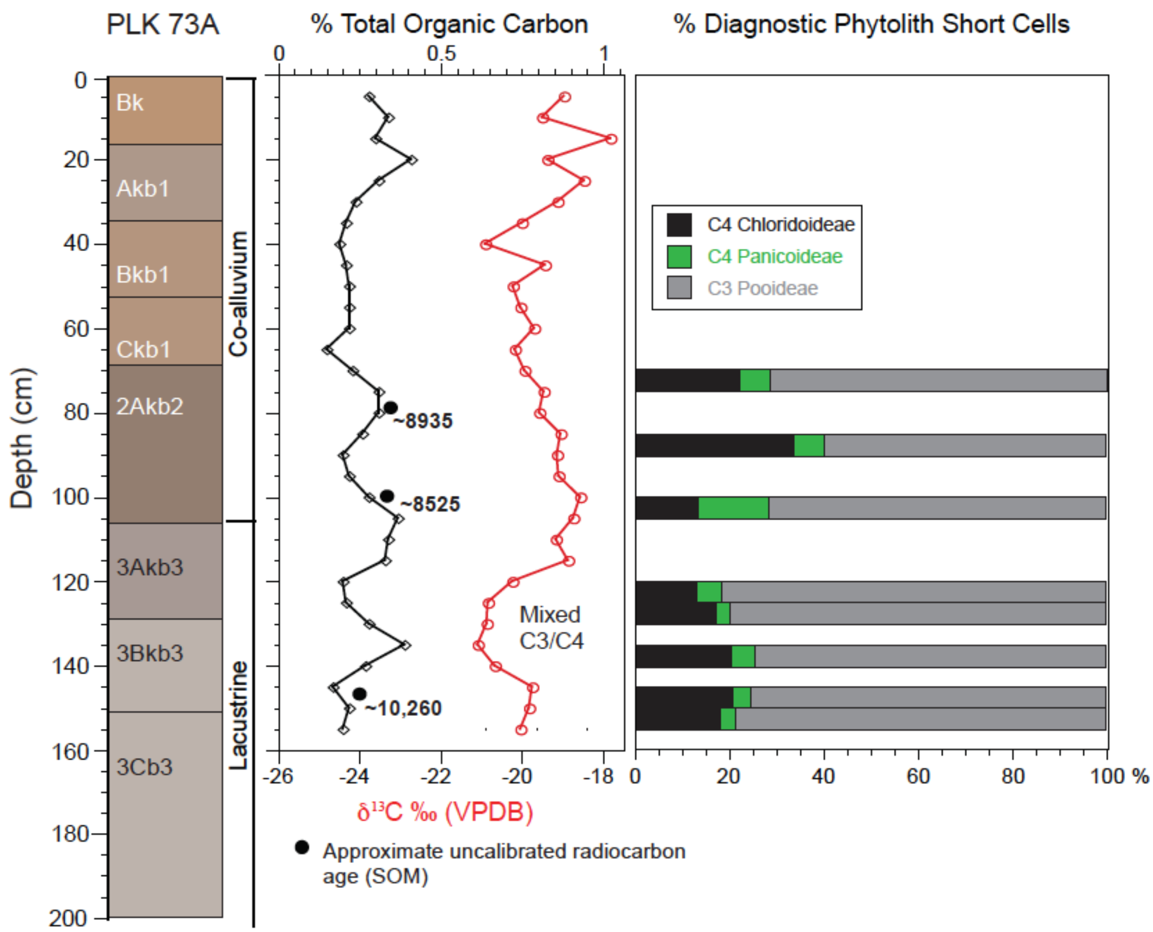

Figure 4. Soil stratigraphy, total organic carbon, stable carbon isotopes, and normalized short-cell phytolith results for the upper reaches of Spring Creek at PLK locality 73, Profile A.

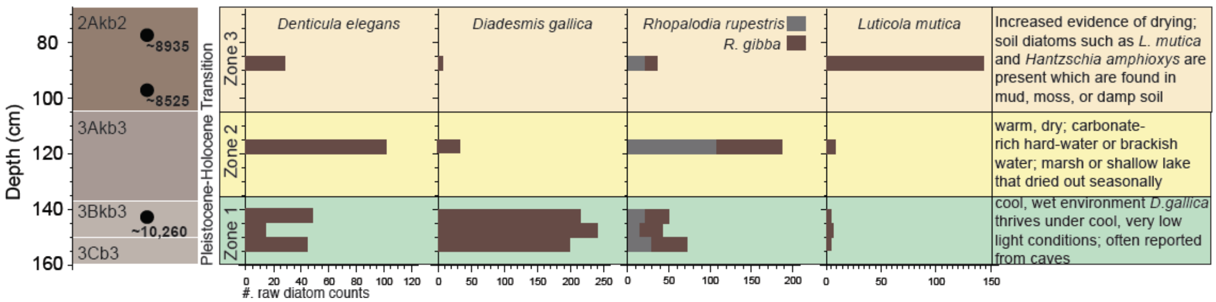

Figure 5. Seventy-four diatom taxa were identified from five soil samples from buried soils in Middle Creek (PLK73-A), with three climate "zones" interpreted. The diagram shows the five most abundant taxa.

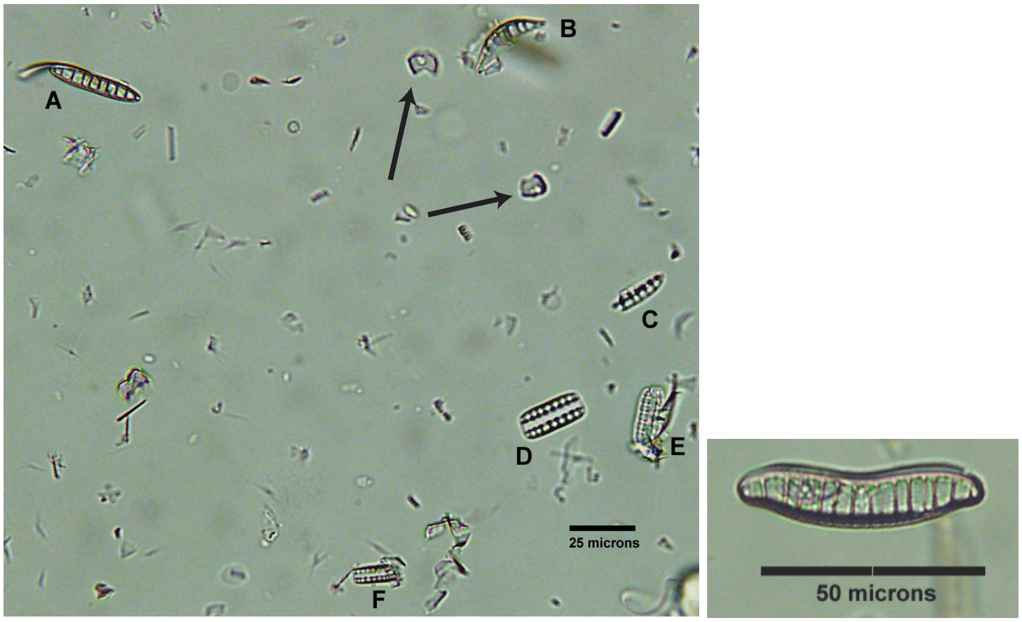

Figure 6. Left: Biogenic silica from the 3Akb2 horizon (125-130 cm below surface), PLK locality 73, Profile A in upper Middle Creek. Arrows: Phytolith short-cells. A-E. *Denticula elegans*, F. *Rhopalodia s*. Right: *Epithemia argus*, one of the most common species in Late Quaternary lacustrine sediments on the Southern High Plains; relatively stable, vegetated lacustrine conditions, but is rare here.

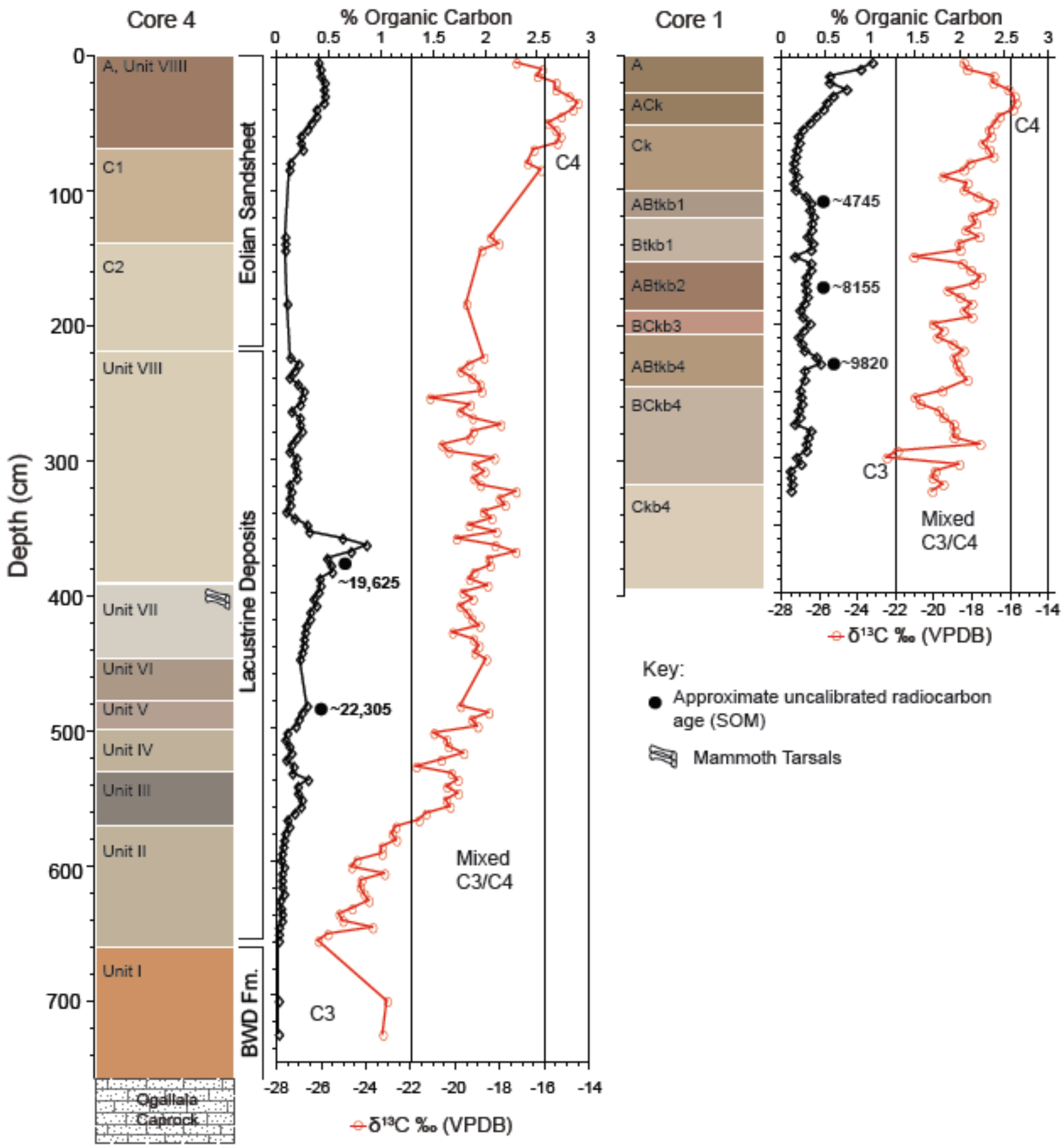

Figure 7. Macy locality 31, Cores 1 and 4 soil stratigraphy, radiocarbon ages determined on soil organic matter, percent total carbon, and stable carbon isotopes.

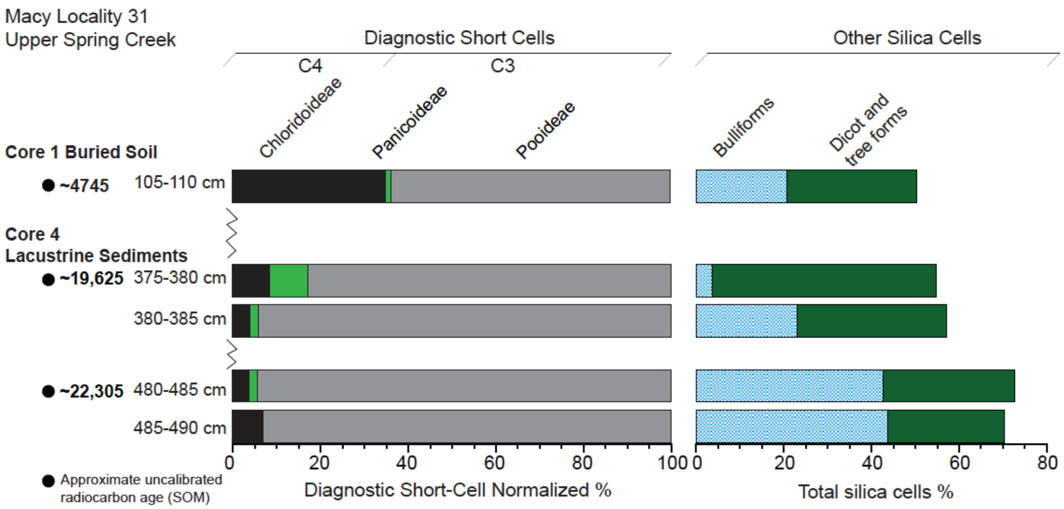

Figure 8. Percentages of normalized short-cell grass phytoliths, bulliforms (produced by grasses), and unknown silica forms likely produced by shrubs/trees from Cores 1 and 4, representing laterally-inset fills from the Pleistocene and Holocene at Macy locality 31 in the upper reaches of Spring Creek.

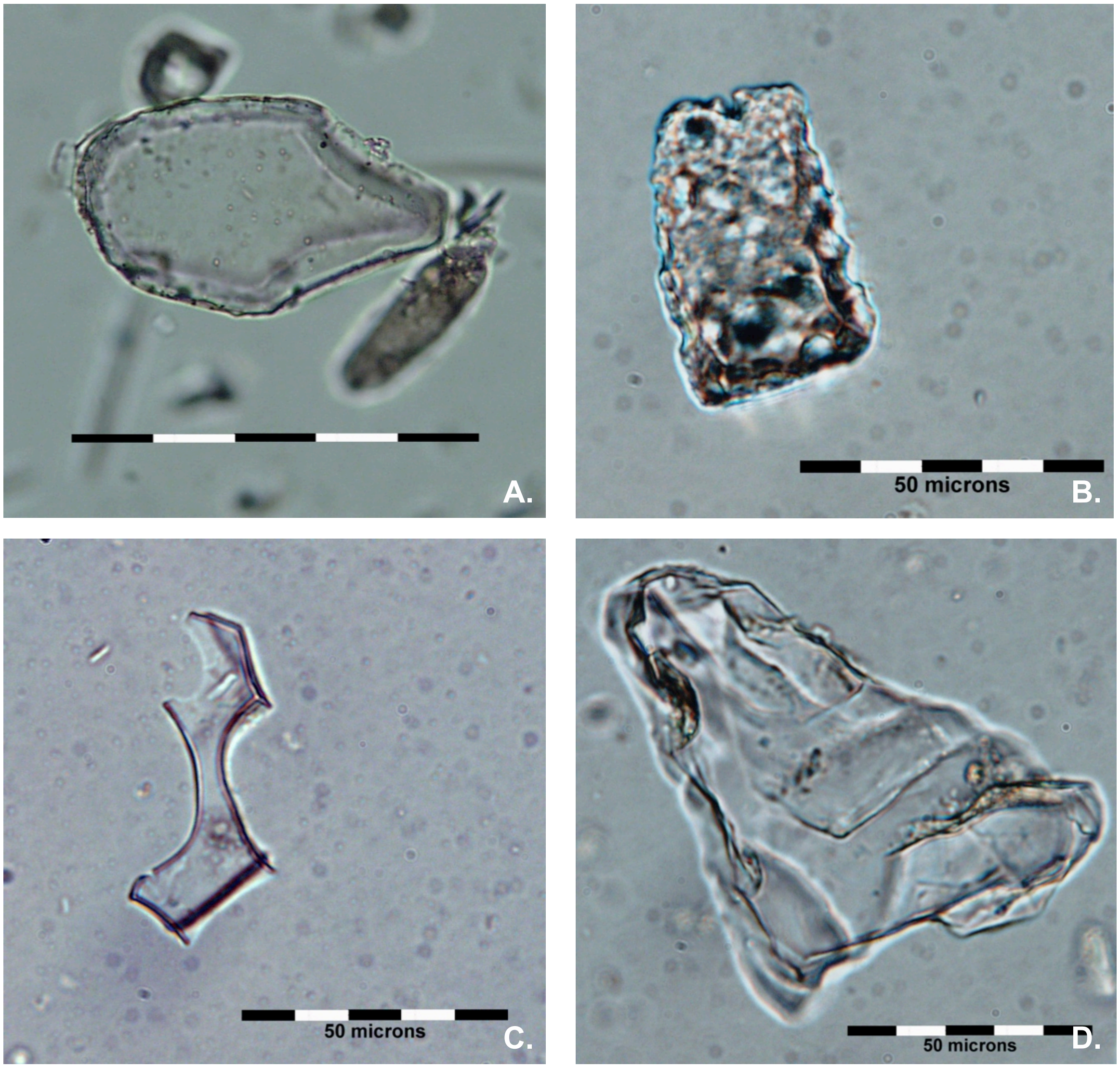

Figure 9. Biogenic silica from buried Pleistocene lacustrine sediments (Core 4) near the upper reaches of Spring Creek at Macy locality 31. A: Well-preserved bulliform cell (485-490 cm); scale bar is 50 microns. B. A degraded bulliform cell with solution pitting. C. Biogenic silica fragment, possibly from a tree or shrub. C. Large biogenic silica fragment possibly from a tree or shrub.

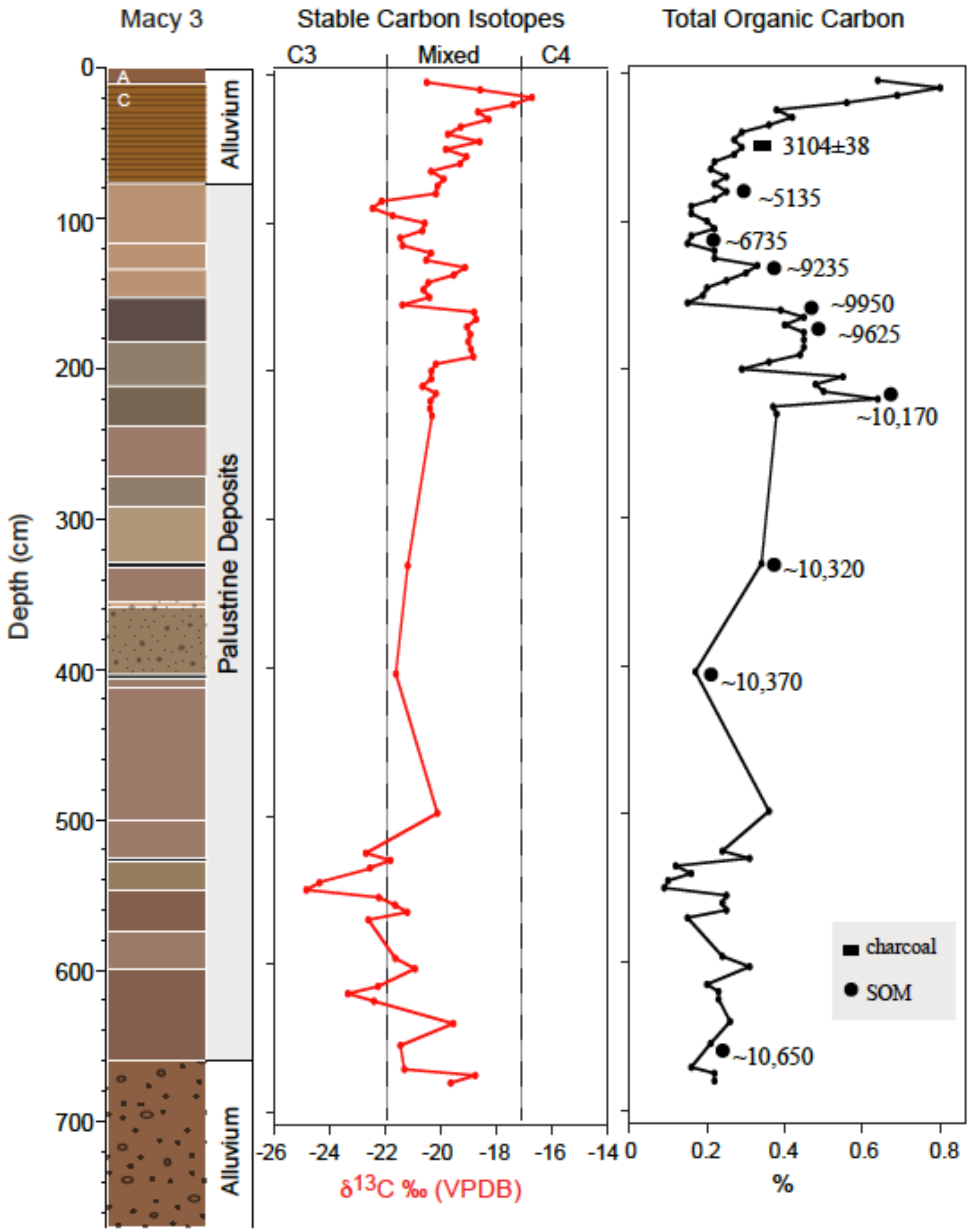

Figure 10. Macy locality 3 core from middle Spring Creek, soil stratigraphy, radiocarbon chronology, stable carbon isotopes, and total organic carbon.

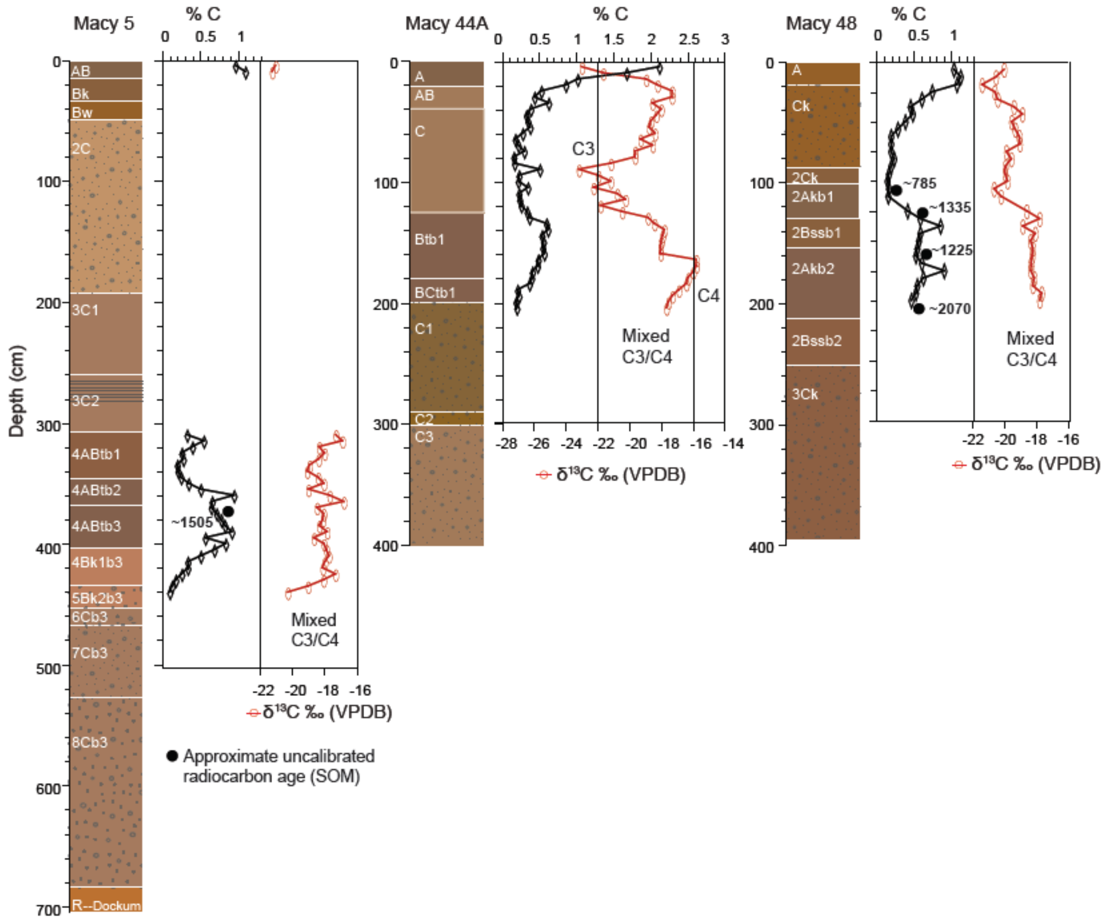

Figure 11. Soil stratigraphy, radiocarbon chronology, stable carbon isotopes, and percent total organic carbon for late Holocene fills South Fork.

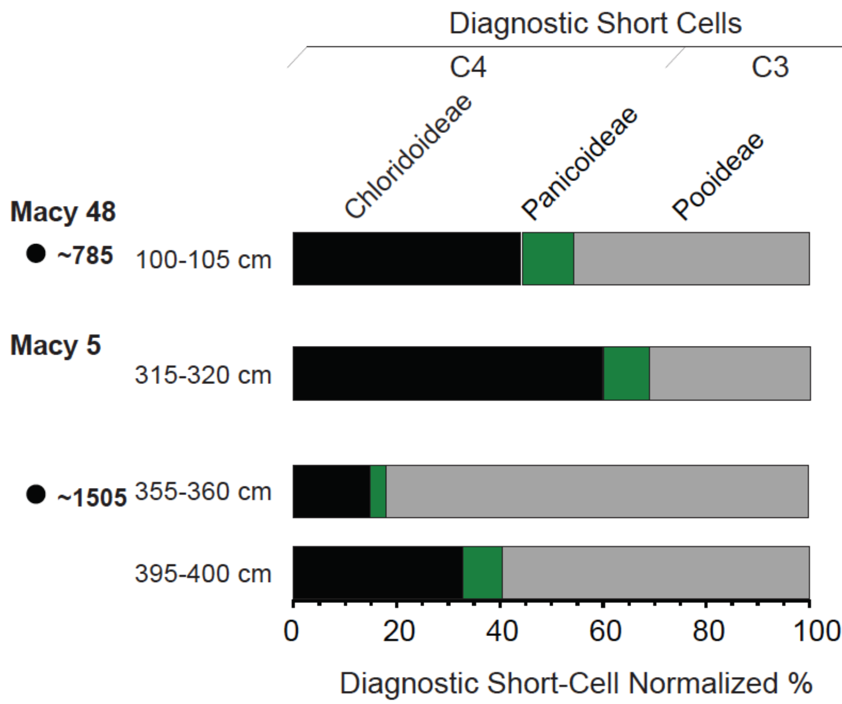

Figure 12. Short-cell phytolith results from Late Holocene soils at Macy localities 48 and 5.

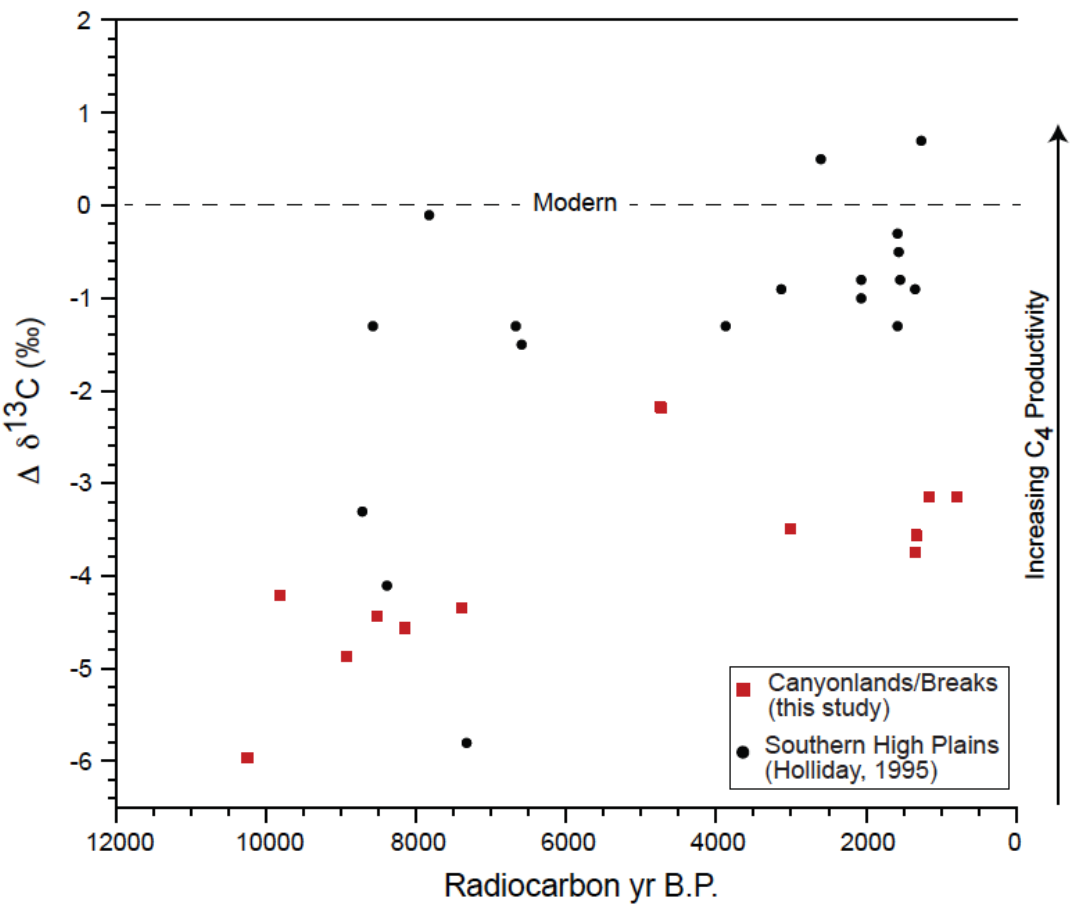

Figure 13. The $\Delta\delta^{13}C$ values from Table 1 plotted with time, comparing the buried soils data reported from draws throughout the Southern High Plains to the data from the canyonlands study area buried soils.

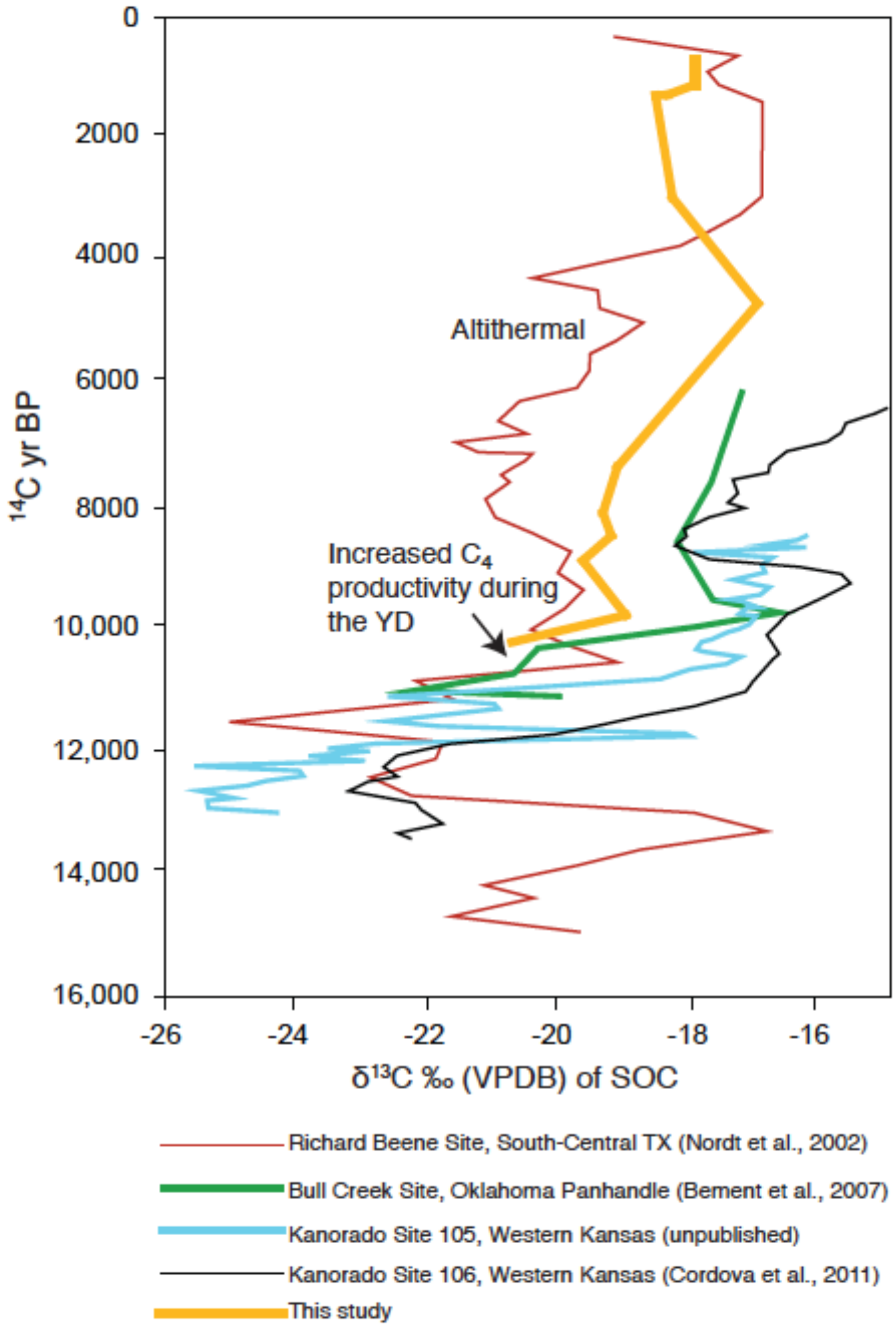

Figure 14. The $\delta^{13}C$ record from this study's buried soils (thick orange line) compared to the $\delta^{13}C$ record for the Kanorado locality (sites 14SN105 and 14SN106) in western Kansas (Cordova et al., 2011 and unpublished), Bull Creek in western Oklahoma (Carter et al., 2009), and the Richard Beene site in south-central Texas (Nordt et al., 2002).

CHAPTER 4

Quantifying Archaeological Preservation Bias using a Universal Model of Soil Erosion: Implications for Hunter-Gatherer Land-Use Intensification and Populations

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Abstract

Erosion and weathering are destructive processes that shape the archaeological record, leaving relatively young cultural materials over-represented at the land surface. Archaeologists often accept this taphonomic or preservation bias as a limitation to archaeological knowledge. Yet, archaeologists base human population estimates on radiocarbon frequency distributions, which depend on site discovery (see Kelly et al., 2013). With population estimates tied to site discovery and numerical dating, it is critical to measure erosion bias and correct human population estimates based on potential sites lost. Unlike the global volcanic model of Surovell et al. (2009), or the stratigraphy-based model of Ballenger and Mabry (2011), we approach the preservation bias problem at the exposed surface, or the archaeological landscape encountered during systematic surface surveys. In our model, we use the Revised Universal Soil Loss Equation (RUSLE) to estimate average annual soil loss, and we use prehistoric population estimates in North America based on Peros et al. (2010). We present a method for calculating prehistoric human demographic changes where we correct for preservation bias after determining the density of hearth features from landform surfaces of known ages. We tested our model in a 33,000-acre portion of an erosive landscape in northwest Texas where surface survey spanning five landform surfaces yielded 385 hearth features. Based on a new equation that estimates population based on erosion and hearth density, results show population rapidly expanding during the Middle Archaic and then steadily increasing through the pre-Contact period. This

trend does not match the current radiocarbon frequency distribution of hearths from the study area. Thus, we believe that erosion is removing Archaic-aged hearths, but in this first approximation, we cannot rule out the possibility that population density is changing differently than the model expects, or that there is a change in human adaptation or use of the landscape. Nevertheless, our model provides a methodology for quantifying archaeological preservation bias. When we understand the extent to which the archaeological record has been affected by erosion, we can make more substantiated conclusions about the archaeological patterns on the surface that inform us about human behavior.

Keywords: taphononmic bias, archaeological demography, land-use intensification, RUSLE

1. Introduction

Archaeologists make inferences about human behavior based on the preserved physical evidence on the landscape. Moreover, archaeological demographers estimate human population density and growth based on the large number of available reported ^{14}C ages from cultural contexts, mostly determined on charcoal (Gkiasta et al., 2003; Buchanan et al., 2008; Chamberlain, 2009; Peros et al., 2010). But the preserved cultural expression has been subjected to site formation processes from both human and natural agents (Schiffer, 1972; 1987). Erosion and weathering are natural destructive processes creating "taphonomic bias," or the "tendency for younger things to be over-represented relative to older things in the archaeological record" (Surovell et al., 2009:1715; Surovell and Brantingham, 2007). Moreover, both human intervention (i.e., fuel choice and combustion processes) and natural taphonomy affects the representativeness of charcoal and other datable materials at archaeological sites (Thery-Parisot et al., 2010). Archaeologists often accept taphonomic bias along with "discovery bias" and "scientific bias" (Ballenger and Mabry, 2011) as a limitation to archaeological knowledge (e.g.

Milburn et al., 2009; Crawford, 2011) even though it affects the outcome of data collection during survey, sampling, and excavation. For example, with land-use intensification inferred from increasing populations (Thoms, 2009), and population estimates tied to site discovery and numerical dating, it is critical to measure erosion bias to correct for potential sites lost.

Recent modeling has advanced our understanding of the impacts of taphonomic bias. However, unlike the global volcanic model of Surovell et al. (2009), or the stratigraphy-based model of Ballenger and Mabry (2011), in this work, we approached the problem at the exposed surface, or the archaeological landscape encountered during systematic pedestrian surface surveys on landforms of different ages. We went further than previous conceptual or qualitative geoclimatic and geoarchaeological assessments of the landscape (see Blum, 1989; Blum et al., 1992; Waters and Kuehn, 1996; Mandel, 1995; Beeton and Mandel 2011) by using the Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1991; Renard et al. 1997) to calculate the flux of soil loss.

In this work, we quantified average annual soil loss, modeled the impact of soil erosion on hearth density in the study area, and developed an equation for correcting taphonomic bias in the population estimates of Peros et al. (2010). In other words, the aim of model development was to determine how erosion, which works to remove hearths, and population density, which accounts for the people producing hearths, interacts to produce the hearth density archaeologists encounter on landform surfaces of different ages. We tested our model in a portion of an erosive landscape known as the “Escarpment Breaks” or “Caprock Canyonlands” (hereafter canyonlands) at the edge of the Southern High Plains in northwest Texas. A ~13,678-ha (~33,800-acre) ranch that was targeted for systematic pedestrian survey because the preserved surface expression of the cultural landscape has remained relatively unaltered by modern human activity (i.e. farming, oil production) in the survey area (Figure 1). Fire-cracked rock (FCR) or hearth features were the ubiquitous feature recorded on the landform surfaces. Currently, 385 hearth features have been recorded (Figure 2) and 22 have yielded ^{14}C radiocarbon ages determined on charcoal and soil organic matter (residue and humates) from hearth fill (Figure 3, Table 1).

In this work, modeled estimates of population based on hearth frequency after accounting for the effects of erosion showed a rapidly expanding population during the Middle Archaic that steadily increased through the pre-Contact period. This trend, however, did not match the current radiocarbon frequency distribution of hearths from the study area, which shows an abundance of hearths in the Protohistoric with fewer hearths during the Archaic. Thus, we believe that erosion has removed Archaic-aged hearths. Reconciling predictive models with archaeological data should allow for more substantiated conclusions about the archaeological patterns that inform us about human behavior.

2. Background

In general, archaeologists assume hunter-gatherers become less mobile, more sedentary, and intensify their use of the land from the late Pleistocene through the Holocene. Intensification refers to “any tactical or strategic practices that increase the production of food per unit area” (Binford, 2001: 188). Fire-cracked rock (FCR) features such as hearths, earth-ovens, steaming pits, and grills may reflect intensification of food processing per unit area; therefore, FCR features may indicate increased sedentism and land-use intensification (Thoms, 2003; 2008; 2009; Johnson and Hard, 2008). In other words, some archaeologists assume that increases in FCR on the landscape equate to hunter-gatherers expending higher amounts of energy to exploit plant foods that require cooking or boiling rather than relying on higher caloric meats from hunting. The additional energy expenditure to collect and process plant foods with low caloric values is likely due to increased population pressures and/or smaller hunting territories (Freeman, 2007). According to the Thoms' (2009) model, "population packing", or the increase of a human population on the landscape, triggered cook-stone propagation and therefore land-use intensification beginning by about 8,000 yrs B.P. (Figure 4). Less is known about how climate-driven pressures impact land-use intensification, but Thoms (2009) notes that the increased frequency of earth ovens from the southern Plains (Edward's Plateau) contrasts with climate oscillations (Bousman, 1998; Nordt et al., 2002). Thus, archaeologists assume a strong link between increasing populations, decreasing territories, and an increase in plant cooking facilities on the landscape.

Because the link between FCR features and land-use intensification depends on locating preserved hearth features, it is appropriate to compare the archaeological record to the geomorphic record as one way of assessing the strength of the link in a given study area, but this is rarely addressed in a meaningful or quantitative way. For example, in southern California "the period-by-period patterning of radiocarbon ages and other heated rock data is likely biased by greater visibility and accessibility of later-period deposits relative to earlier deposits" (Milburn et al., 2009: 6), and hearth feature distribution "may be due to differential preservation, excavation and data recovery techniques, and the nature of the archaeological record" (Crawford, 2011:4). These studies do not attempt to assess the impact of the bias, or how visibility and accessibility impact archaeological interpretation.

Interpretation of human behavior from the physical attributes of fire-cracked rock or hearth features themselves takes many forms, which are important contributions to anthropology. For this study, hearth features "comprise any discrete structure with contemporaneous evidence for burning and human activity" (Backhouse and Johnson, 2007c: 176). Raw material sources for hearthstones can be used to infer distance of transport (Hurst et al., 2009). Hearth size and shape can be used to infer volume of processed food (Wandsnider, 1997) and duration of use (Thoms, 2009). Cooking function of the hearth (i.e. earth oven versus grill) is inferred from number, volume, and type of hearthstone (Yu, 2006; Thoms, 2009; Crawford, 2011). Also, degree of char and wear on a hearthstone can reflect hearth function, duration, and re-use (Thoms, 2008). For example, boiling stones used repeatedly have a greater degree of wear. Thus, changes in cook-stone technology or function inferred from changes in various physical attributes of hearth features that are visible in the archaeological record tell us a number of other aspects of human behavior; some of which have been linked to intensification, while in other areas, such as western New South Wales, Australia hearth features have not been linked to intensification (Holdaway et al., 2008). Nevertheless, archaeologists care about hearth features and their integrity because they are used to make inferences about a number of human behaviors.

Based on Thoms' (2009) hot rock cooking study, intensified land-use on the Southern Plains is tied to increases in hunter-gatherer populations around 8,000 B.P. Radiocarbon frequencies determined from hearth and other cooking features show increased frequency of earth oven use over time, peaking at 1500 B.P. (Thoms, 2009). Compiled radiocarbon date frequencies from hearth data in central Texas (Decker, 1997; Dering, 2003; Mauldin, 2003; Freeman, 2007), eastern trans Pecos (Mallouf, 1985), and the post oak savannah (Fields, 2004) all show significant increases in hearth features beginning around 2,000 B.P., and peaking around 1,500 B.P., which is comparable to Thoms (2009). This amplification of cooking practices could have been to buffer against other resource decline and/or population increases. Subsequent decline of hearth features, then, could be from population loss, cultural/behavioral reorganization, over-exploitation of the landscape, or forces of climate that are impacting resources.

Efforts to understand prehistoric population dynamics for North America over time have been modeled by archaeological demographers, relying on summed probability distributions of radiocarbon ages (Chamberlain, 2009). Acknowledgement of caution and limitations such as taphonomic bias are fairly well accepted with this method as a way to infer general population trends (Surovell et al., 2009; Ballenger and Mabry, 2011). However, smaller-scale variations within the trend, such as a Younger Dryas-associated "Clovis collapse" are more problematic because of calibration curve effects (Bamforth and Grund, 2012). The Peros et al. (2010) model, however, is the most robust because it is based on 25,000 ^{14}C ages for the Paleoindian to Contact periods from a variety of landscapes and settings (Figure 5; re-drawn to reflect number of people per hectare). The model reflects steady population increases over time since 10,000 B.P., before populations explode around the time of the adoption of agriculture. Given the robust suite of radiocarbon ages across a very large area, the preservation bias effects are minimal. Thus, the Peros et al. (2010) data represents the current best estimate of prehistoric North American population estimates.

3. Modeling Preservation Bias

In this first approximation, global parameters for hearth features were selected while alterations were made on both the soil erosivity factor "A" (average annual soil loss per year) and population density. The A-factor was determined from the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1991; 1997). Population density was based on estimates by Peros et al. (2010) where after converting to people per hectare, the minimum population estimate (Pop_{min}) was 0.00001 people/hectare and the maximum population estimate (Pop_{max}) was 0.0005 people/hectare (Figure 5).

The Revised Universal Soil Loss Equation (RUSLE) (Renard et al. 1991, 1997) provides estimates of average annual soil loss (A) from the surface due to water (sheet and rill) erosion based on five factors: rainfall runoff erosivity (R), soil erodibility (K), slope length (L), slope steepness (S), cover management (C), and support practice (P). First developed by Wischmeier and Smith (1965) as "USLE" to estimate erosion and manage conservation planning for agricultural fields, the equations for determining each factor were revised to handle seasonality, a greater variety of land-use, and larger study areas with more complex topography (Renard et al. 1991). Using ArcMap to calculate each factor, a range of average annual soil loss values calculated for the study area were used where A_{max} = 0.01 cm/year and A_{min} = 0.1 cm/year.

In order to study the effect of erosion, population density, and time on hearth density and to develop a correction equation to account for taphonomic bias when estimating population density from discoverable hearths on a landscape, we developed a probabilistic model of the form:

$$P_H = 1 - \left(1 - P_C\right)^{N_P/N_H}$$

where P_H represents the combined probability that N_P number of people within a given simulated area will construct at least one hearth over a specified time interval, N_H is the average number of people that one hearth supports and, thus, the quotient, N_P/N_H, is the number of groups within the area that each have a probability, P_C, of constructing a hearth over the specified time interval. The value for N_H was set at 5, although it could be as large as 9 people based on estimates from Binford (2001); those estimates, however, are based on ethnographic data. This count was used as a starting point, and highlighted as a parameter for future model refinement.

The probability of a single group constructing a new hearth per year (P_C) was set at 0.8 to factor in potential hearth reuse and avoid population overlap.

One hundred Monte Carlo realizations were run for each of four landform surface ages: 10,000 B.P. (uplands), 5,000 B.P. (eroding slopes), 1,000 B.P. (high terrace), and 500 B.P. (low terrace). For each realization, the equation above was used to stochastically simulate the addition of a hearth each year on the landform while the RUSLE-calculated soil loss was used to remove hearths from the landform. In each simulation, landforms were set to a size of 200 ha and hearth vertical thickness was assumed to be constant and set to 10 cm such that if a landform surface had a RUSLE-modeled cumulative soil loss greater than 10 cm from the time step of the addition of the hearth, the hearth would have been completely eroded or so degraded from its original form as to be undiscoverable by surface survey. We also included an erosion retardation factor of 0.5 in the simulations that can be interpreted as the total fraction of the landform affected by erosion for that year. We assumed that the values of soil loss calculated from RUSLE do not hold for an entire landform uniformly and, therefore, we chose a midpoint value between zero (erosion not affecting the land surface) and one (erosion affecting the surface uniformly) reflecting this assumption. Currently, the model does not account for hearth burial due to erosion from upslope areas.

4. Methods

Model development and data analyses were conducted with R 3.1.2 (R Development Core Team, Vienna, Austria); four simulations were conducted where erosion and population parameters were altered. The purpose of the simulations is to reveal the potential number of hearths eroding away from 4 different landform surfaces given rates of erosion and numbers of hearths being built based on population. Estimated ages of the four landform surfaces for the study area are based on the radiocarbon chronology from buried soils in the study area reported by Murphy et al. (2014) and dated hearth features (n=22) with good integrity (i.e., not deflated) (Table 1). The ages are reported in uncalibrated ^{14}C years B.P. (Table 1). Multiple charcoal samples and associated hearth fill matrix samples were taken stratigraphically (vertically) from each of the 22 hearths during excavation. Radiocarbon ages from each hearth were averaged to provide an approximate age to plot in Figure 3. All archaeological features and isolated finds were mapped with a Trimble GPS during a full (100%) surface survey of the study area; hearth features were plotted using ArcMap (Figure 2).

To calculate the RUSLE equation (A = RKLSCP) in ArcGIS, we gathered the data for each factor for the study area using a 30 m digital elevation model (DEM), converting to raster, and then multiplying the factors together using raster calculator (Figure 6). Soil Data Viewer 6.0, an add-in to ArcMap, was used to extract soil erodibility data (K-factor) for Garza County, Texas. Climate data for Garza County, used to calculate R-factor, was obtained from the RUSLE2 program (USDA, 2014) where annual precipitation is 20.8 inches and the R-factor is 130. The C-factor was determined from the National Landcover Dataset for Texas (Geospatial Data Gateway, 2006); the DEM was joined with a table of corresponding landcover C-factors from USDA Agricultural Handbook 537 (Wischmeier and Smith, 1978). To determine the slope length and steepness (LS) factor, the Arc Macro Language AML code (http://www.onlinegeographer.com/slope/slope.html) developed by Hickey (2000) and van Remortel et al. (2001, 2004) was implemented following Khosrowpanah et al. (2007). Since there was no land management practice for the study area, P was set at 1. Raster calculator in ArcGIS was used to calculate A, or tons of acres per year; values were converted to units of length (cm/year).

5. Results

5.1 Simulation 1: Population and erosion constant and minimum over 10,000 years

In simulation 1, there are equal populations through time and equal erosiveness through time for the four landforms of different ages. For erosion, we assume there is no change in climate and no inherent properties in the soils that would make one landform more susceptible to erosion than another. The minimum average annual population was set to 0.00001/ha (1 person/100 km^2) and the minimum erosion potential for the study area was set to 0.01 cm/year. As expected, results show mean hearth densities (number per hectare) are lower on landforms of younger age (Figure 7). In other words, there are more hearths on a landform surface that dates to 10,000 years B.P. than 500 years B.P. because of the amount of time the older landform has been subjected to minimal erosion. For younger landforms, there are lesser opportunities for people to construct hearths. This modeled preservation bias is different that what is observed in the archaeological record, where more hearths are typically recorded on the land surface at 500 B.P. than 10,000 B.P.

5.2 Simulation 2: Population density constant minimum, erosion decreases over time

In the second simulation, population was set at the constant minimum: 0.00001 people/ha over time. Erosiveness decreases linearly through time from the maximum 0.1 cm/yr at 10,000 B.P. to .01 cm/yr at 500 B.P. Thus, there is more erosion in the past then present; an analogy to this would be the external erosion forces caused by climate during the warm, dry middle Holocene Altithermal. Despite heavy erosion on older landforms, mean hearth density is still higher at 10,000 B.P. and decreases over time (Figure 8). However, mean hearth densities decreased compared to simulation 1 because as erosion is larger in simulation 2, more hearths are being eroded away. Even though population remained constant, based on these hearth density results, population appears as though it is decreasing over time.

5.3 Simulation 3: Erosion constant minimum, population increases over time

In simulation 3, erosion is constant and minimum at 0.01 cm/year while the population is increasing over time based on the Peros et al. (2010) estimates (Figure 9). With minimum erosion acting on preservation, one can assume archaeologists can make more accurate inferences from the observed archaeological record. Results show low mean hearth densities with low populations at 10,000 B.P., and a spike in hearth densities at 1,000 B.P. This result is similar to the compiled radiocarbon frequency data from Texas cook-stone features that show a peak between 2,000 and 1,000 B.P. However, these results are dissimilar to the radiocarbon age distribution from hearth features in the study area that show a peak during the Protohistoric period.

5.4 Simulation 4: The interaction of erosion and population density

In simulation 4, twenty population levels between the population minimum and maximum, and twenty erosion values between A_{min} and A_{max}, were run to produce a hearth density predicted from the model that we might expect to observe on the landscape (Figure 10). The simulation was run for 10,000 years and discretized every 500 years. The output results in 400 unique data points combining erosion and population within the value constraints for each landform to produce a predicted hearth density. Results show that for low populations, effects from erosion are minimal; there are simply not many hearths for erosion to remove from the land surface. For high populations, however, the relationship between hearth density and population is highly influenced by erosion and this effect becomes more pronounced the older the surface. For younger surfaces (i.e., 1,000 and 500 B.P.), there is less time to develop high concentrations of hearths despite there being a much higher population and thus the erosion effect is more muted than older surfaces.

The results from simulation 4 (Figure 10) show that estimating the true population from hearth density clearly depends on the erosion intensity and the amount of time that that erosion has been operating on the land surface. Within the study area, there is as much as 10-fold the amount of erosion taking place in some areas over others. This has a major effect on hearth preservation. But even if erosion is constant across the land surface, the probability of hearth building based on the amount of time the land surface has been exposed has to be taken into account when estimating population density from observed hearth density. In other words, population drives hearth density until erosion takes over and obliterates the pattern. Nevertheless, effects of population and erosion are muted on younger surfaces because of the time factor, which tends to over-represent younger sites. On exposed landform surfaces that are subjected to repeated cultural occupation over millennia, the "palimpsest effect," or the archaeological overprinting that occurs over time, is apparent (Figure 11). With a constant population and erosion rate, there is simply much more time for people to build hearths on a surface that remains exposed for 10,000 years compared to younger surfaces (i.e. 1,000, 500 B.P.).

5.5 Population Equation

We applied a multivariate linear regression using the dataset from simulation 4 to predict the actual population density (D_P), from 3 parameters: time on the landscape (t), hearth density (D_H), and landform erosion (E) (Figure 12); this produced an equation that accounts for each term and their interactions:

$$D_P = 1.86\times10^{-3} D_H + 1.35\times10^{-3} E + 8.39\times10^{-9} t + 8.11\times10^{-2}\left(D_H \times E\right) - 1.08\times10^{-7}\left(D_H \times t\right) - 1.29\times10^{-7}\left(E\times t\right) + 2.03\times10^{-6}\left(D_H \times E \times t\right)$$

where D_P is given in units of number people per hectare, t is given in years, D_H is given in number of hearths per hectare, and E is given in centimeters of soil loss per year. The multivariate linear regression reconstructs population and accounts for 90% of the variation in the true population as given in the simulation.

Using the above equation, we used hearth density, RUSLE-modeled erosion values, and estimates of age for each landform determined for the study area to produce a predicted population for the Caprock Canyonlands study area (Figure 13). The results do not compare well to the radiocarbon frequency distribution of hearths from the study area (Figure 3); population remains low until dramatically increasing during the Middle Archaic and steadily increasing through the pre-Contact period. Although we cannot rule out that there is a change in human adaptation or use of the landscape, we believe that erosion is removing Archaic-aged hearths.

6. Discussion

An initial sample of radiocarbon ages (n = 22) from hearth features across the canyonlands study area landscape shows a peak in hearths during the Protohistoric period. These results from the study are unlike regional Texas radiocarbon frequencies from hearth data (see Mallouf, 1985; Decker, 1997; Dering, 2003; Mauldin, 2003; Fields, 2004; Freeman, 2007; Thoms, 2009) that show dramatic increases in hearth densities between 2,000 and 1,000 B.P. before a subsequent decline. Radiocarbon frequency results from the study area would suggest that Middle Archaic populations were low and Protohistoric populations were high, when in reality, our model shows that erosion has removed hearths during the Middle Archaic period.

If the canyonlands served as a habitat-focused use area, we would expect that in times of severe drought on the Southern High Plains that population and hearth features would increase within the canyonlands, i.e. during the xeric middle Holocene Altithermal. Paleoclimate data for the Caprock Canyonlands study area show a mixed C_3/C_4 plant community that persisted throughout the Holocene, and includes areas of palustrine and lacustrine deposits. The study area was never under a C_4 short grass prairie like the Southern High Plains and offered protection from the wind and more access to spring water and readily available Ogallala caliche materials (Hurst et al., 2008). Whereas Thoms (2009) notes that the increased frequency of earth ovens from the Southern Plains (Edward's Plateau) contrasts with climate oscillations (Bousman, 1998; Nordt et al., 2002) and therefore is a strong indicator of land-use intensification, the population within the study area itself is more reflective of the patterns of intensive erosion. Thus, it is not likely that land-use intensification peaked in the Protohistoric period within the study area. Based on the model, hearth construction may have taken place at a higher rate in the canyonlands during the Middle Archaic, at a time when the Southern High Plains were experiencing their most xeric conditions. One way to incorporate the impact of climate on human behavior, as an alternative to increasing populations without intensification, would be to test moisture and temperature data derived from multiple proxies to see if populations within the canyonlands coincide with periods of high effective moisture and moderate temperatures (see Kelly et al., 2013).

6.1 Model refinement

From this first approximation, we cannot rule out the possibility that there is a change in human adaptation or use of the landscape different from land-use intensification. Future refinement of the model could potentially adjust for human site selection bias or seasonal use, the number of people per hearth or number of hearths could be altered, and we could attempt to measure not simply population density but land-use intensification itself, based on the assumption that population packing occurs immediately prior to land-use intensification (Binford, 2001; Thoms, 2009). Furthermore, soil loss does not occur uniformly across and land surface over time (Wang et al., 2000), so the next step would be to incorporate surface roughness using the standard deviation of elevations on each landform to adjust for how erosion impacts the landform, and to adjust the erosion factor for known climate changes through the Holocene. Finally, this model does not account for deposition. Because of the nature of the highly erosive landscape, soils and most sediments have been completely flushed out of the study area; only co-alluvial fans are zones of net sediment storage (Murphy et al., 2014). The Unit Stream-Powered Erosion/Deposition model (Mitasova et al., 1996), which incorporates both erosion and deposition, could be a future way to validate the RUSLE estimates for erosion presented here.

7. Conclusions

This paper demonstrates that archaeological preservation or taphonomic bias can be quantified via models, which can then be tested against field data. The results of our study underscore the notion that taphonomic factors operate in all times and places; the nature of the acting factors can be site-specific and must be evaluated separately (Bamforth and Grund, 2012: 1773). Archaeological materials subject to natural site formation processes should not be dismissed as a limitation to archaeological knowledge. In this first approximation, model results show how erosion changes the relationship between population and hearth density over time. The effects of population and erosion are muted on younger surfaces because of the time factor (preservation bias). The model testing shows Archaic-aged hearths have been mostly removed on eroding slopes, meaning that Archaic-aged hearths, and thus the related population proxy, are under-represented in the study area. Thus, we must continue to model and refine our understanding of taphonomic or preservation bias. Continued refinement of the model presented here can be a way forward to better determine if inferences about population increases from hearth densities on the landscape reflect land-use intensification, or some other factors such as habitat focusing during regional droughts. In sum, archaeologists need to model perseveration biases to complement any hearth density (or site density) study in order to paint a clearer picture of human land-use, behavior, and population.

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Table 1. Radiocarbon age results for 22 hearth features within the Caprock Canyonlands study area.

Sample Locality & Feature Number	Fraction	Uncalibrated yr B.P.	Error Range	δ13C ‰	Elevation (base)	Dating Type	Arizona Lab Number
PLK Locality 4 (41GR736)							
FPLK4-5							
CPLK4-2	charcoal	**2005**	**+250/-240**	-24.5	10009.25	conventional	14465
PLK Locality 19 (41GR706)							
FPLK19-1							
CPLK19-5	charcoal	**3110**	**35**	-21.4	81470.1	AMS	14466
CPLK19-12	charcoal	**4360**	**160**	-23.0	81456.1	conventional	14468
CPLK19-8	residue	3720	+55/-50	-22.4	81463.5	conventional	14502
CPLK19-8	humates	**4490**	**+/- 5**	-22.4	81463.5	conventional	14502.1
CPLK19-9	charcoal	**2745**	**35**	-22.6	81453.4	AMS	14467
CPLK19-6	residue	2550	+/- 45	-21.1	81451.9	conventional	14501
CPLK19-6	humates	**4060**	**+/- 65**	-21.9	81451.9	conventional	14501.1
FPLK19-2							
CFPLK19-2-8	charcoal	**3415**	**+/- 30**	-23.9	81322.5	AMS	15173
CFPLK19-2-1	residue	3495	+/- 60	-22.6	81320.0	conventional	15210
CFPLK19-2-1	humates	**4110**	**+/- 90**	-22.9	81320.0	conventional	15210.1
CFPLK19-2-9	charcoal	**3935**	**+/- 145**	-23.6	81317.0	conventional	15174
CFPLK19-2-11	charcoal	**4440**	**+110 / -105**	-24.1	81316.0	conventional	15176
CFPLK19-2-2	residue	3635	+/- 60	-22.0	81312.5	conventional	15211
CFPLK19-2-2	humates	**4020**	**+/- 55**	-22.2	81312.5	conventional	15211.1
CFPLK19-2-10	charcoal	**2240**	**+/- 40**	-22.0	81311.0	AMS	15175
CFPLK19-2-3	residue	3650	+/- 50	-22.1	81309.0	conventional	15212
CFPLK19-2-3	humates	**4215**	**+/- 60**	-22.1	81309.0	conventional	15212.1
PLK Locality 34 (41GR680)							
FPLK34-1							
CPLK34-8	charcoal	**4200**	**+/-40**	-24.1	99893.2	conventional	14735
CPLK34-4	residue	895	+/- 80	-19.8	99887.5	conventional	14737
CPLK34-4	humates	**3535**	**+145/-140**	**-21.2**	99887.5	conventional	14737.1
CPLK34-5	residue	2245	+/-60	-20.1	99885.0	conventional	14736
CPLK34-5	humates	**3820**	**+/- 70**	-21.7	99885.0	conventional	14736.1
CPLK34-6	residue	2300	+/- 135	-19.8	99882.5	conventional	14738
CPLK34-6	humates	**3570**	**+95/-90**	-21.6	99882.5	conventional	14738.1
PLK Locality 38 (41GR679)							
FPLK38-2							
CFPLK38-2-1	residue	2210	+/-65	-19.6	99607.5	conventional	15217
CFPLK38-2-1	humates	**2610**	**+135/-130**	-20.5	99607.5	conventional	15217.1
CFPLK38-2-2	residue	1150	+/-85	-19.7	99602.5	conventional	15218

Sample Locality & Feature Number	Fraction	Uncalibrated yr B.P.	Error Range	δ13C ‰	Elevation (base)	Dating Type	Arizona Lab Number
CFPLK38-2-2	humates	**1680**	**+/-105**	-19.7	99602.5	conventional	15218.1
PLK Locality 73 (41GR688)							
FPLK73-1							
CFPLK73-1-5	charcoal	**440**	**+/- 85**	-25.5	99772.5	conventional	15168
CFPLK73-1-6	charcoal	**350**	**+100 / -95**	-25.1	99766.0	conventional	15169
CFPLK73-1-2	residue	POST-BOMB (101.2)	+/- 0.5 pMC	-24.7	99765.0	conventional	15197
CFPLK73-1-2	humates	<195	99.5 +/- 0.5 pMC	-24.6	99765.0	conventional	15197.1
CFPLK73-1-7	charcoal	**290**	**+/- 50**	-25.8	99764.0	conventional	15170
CFPLK73-1-8	charcoal	**300**	**+/- 45**	-26.0	99762.5	conventional	15171
CFPLK73-1-3	residue	100.1 +/- 0.5 pMC		-24.9	99760.0	conventional	15213
CFPLK73-1-3	humates	100.6 +/- 0.5 pMC		-24.3	99760.0	conventional	15213.1
CFPLK73-1-9	charcoal	**255**	**+80 / -75**		99759.5	conventional	15172
CFPLK73-1-4	residue	**85**	**+/- 30**	-24.4	99757.5	conventional	15214
CFPLK73-1-4	humates	100.7 +/- 0.6pMC		-23.9	99757.5	conventional	15214.1
PLK Locality 84 (41GR143)							
FPLK84-1							
CFPLK84-1-1	charcoal	**875**	**+/- 35**	-22.4	100697.5	AMS	15359
CFPLK84-1-2	charcoal	**1340**	**+/-35**	-22.8	100691.0	AMS	15360
Macy Locality 16 (41GR722)							
FMACY16-1							
CFMACY16-1-12	charcoal	**1380**	**+/- 40**	-23.6	99721.5	AMS	15177
CFMACY16-1-14	charcoal	**1515**	**+/- 35**	-23.4	99710.0	AMS	15178
CFMACY16-1-2	residue	845	+/- 40	-20.2	99707.5	conventional	15199
CFMACY16-1-2	humates	**1250**	**+/- 55**	-21.2	99707.5	conventional	15199.1
CFMACY16-1-15	charcoal	**1655**	**+/- 35**	-25.8	99706.5	AMS	15179
CFMACY16-1-18	charcoal	**1775**	**+/- 35**	-22.1	99699.5	AMS	15180
CFMACY16-1-6	residue	1005	+/- 40	-19.0	99697.5	conventional	15200
CFMACY16-1-6	humates	**1600**	**+/- 75**	-19.7	99697.5	conventional	15200.1
CFMACY16-1-21	charcoal	**1715**	**+/- 35**	-24.3	99690.5	AMS	15181
CFMACY16-1-10	residue	1840	+/- 40	-18.7	99685.0	conventional	15201
CFMACY16-1-10	humates	**1900**	**+/- 100**	-19.3	99685.0	conventional	15201.1
CFMACY16-1-23	charcoal	**1815**	**+/- 35**	-16.3	99685.0	AMS	15182
FMACY16-2							
CFMACY16-2-5	charcoal	**1145**	**+/- 35**	-22.6	99720.0	AMS	15183
CFMACY16-2-9	charcoal	**1255**	**+135 / -130**	-23.3	99714.0	conventional	15184
CFMACY16-2-1	residue	795	+/- 40	-19.2	99712.5	conventional	15206
CFMACY16-2-1	humates	**830**	**+/- 90**	-18.7	99712.5	conventional	15206.1
CFMACY16-2-13	charcoal	**1135**	**+/- 95**	-23.4	999710.0	conventional	15185

Sample Locality & Feature Number	Fraction	Uncalibrated yr B.P.	Error Range	δ13C ‰	Elevation (base)	Dating Type	Arizona Lab Number
CFMACY16-2-14	charcoal	**1040**	**+115 / -110**	-23.4	99708.0	conventional	15186
CFMACY16-2-2	residue	**955**	**+/- 45**	-19.6	99707.5	conventional	15207
CFMACY16-2-2	humates	695	+70 / -65	-19.2	99707.5	conventional	15207.1
CFMACY16-2-16	charcoal	**1055**	**+/- 35**	-24.1	99706.5	AMS	15187
CFMACY16-2-18	charcoal	**1125**	**+/- 35**	-26.9	99705.5	AMS	15188
CFMACY16-2-3	residue	**885**	**+/- 45**	-20.5	99702.5	conventional	15208
CFMACY16-2-3	humates	805	+/- 100	-20.3	99702.5	conventional	15208.1
FMACY16-3							
CFMACY16-3-6	charcoal	**1205**	**+/- 80**	-22.6	99793.5	conventional	15258
CFMACY16-3-1	residue	260	+/- 35	-17.0	99790.0	conventional	15215
CFMACY16-3-1	humates	**440**	**+/- 95**	-17.5	99790.0	conventional	15215.1
CFMACY16-3-10	charcoal	1015	125/-120	-22.8	99790.5	conventional	15259
CFMACY16-3-16	charcoal	**1075**	**+125/-120**	-22.6	99787.0	conventional	15260
CFMACY16-3-2	residue	675	+/- 35	-16.3	99785.0	conventional	15216
CFMACY16-3-2	humates	**945**	**+/-105**	-17.2	99785.0	conventional	15216.1
CFMACY16-3-3	residue	915	+55 / -50	-17.7	99782.5	conventional	15209
CFMACY16-3-3	humates	**955**	**+115 / -110**	-17.5	99782.5	conventional	15209.1
Macy Locality 25 (41GR723)							
FMACY25-1							
CFMACY25-1-2	charcoal	**475**	**+/- 35**	-25.1	100606.0	AMS	15261
CFMACY25-1-5	charcoal	**490**	**+/- 100**	-24.8	100603.0	conventional	15262
CFMACY25-1-1	residue	<100 (99.8 +/- 0.5 pMC)		-22.6	100602.5	conventional	15203
CFMACY25-1-1	humates	**270**	**+/- 35**	-23.5	100602.5	conventional	15203.1
Macy Locality 36 (41GR732)							
FMACY36-1							
CFMACY36-1-10	charcoal	**2885**	**+/- 40**	-25.6	99020.5	AMS	15263
CFMACY36-1-02	residue	1385	+/- 80	-17.0	99020.0	conventional	15194
CFMACY36-1-02	humates	**2320**	**+/- 110**	-18.6	99020.0	conventional	15194.1
CFMACY36-1-04	residue	1485	+/- 65	-17.4	99015.0	conventional	15195
CFMACY36-1-04	humates	**3225**	**+/- 100**	-17.0	99015.0	conventional	15195.1
CFMACY36-1-06	residue	1535	+/- 75	-17.0	99010.0	conventional	15196
CFMACY36-1-06	humates	**2985**	**+115 / -110**	-19.2	99010.0	conventional	15196.1
Macy Locality 47 (41GR733)							
FMACY47-1							
CFMACY47-1-3	charcoal	**1270**	**+/- 35**	-23.9	101209.0	AMS	15265
CFMACY47-1-2	charcoal	**1335**	**+/- 35**	-24.4	101208.0	AMS	15264
CFMACY47-1-1	residue	1175	+/- 85	-18.2	101202.0	conventional	15202
CFMACY47-1-1	humates	**1685**	**+175/-170**	-18.2	101202.0	conventional	15202.1
Macy Locality 74 (41GR843)							

Sample Locality & Feature Number	Fraction	Uncalibrated yr B.P.	Error Range	δ13C ‰	Elevation (base)	Dating Type	Arizona Lab Number
FMACY74-1							
CFMACY74-1-01	residue	104.6	+/ -0.6 pMC	-18.7	99673.0	conventional	A-15641
CFMACY74-1-01	humates	<265	99.8 +/ - 1.5 pMC	-19.1	99673.0	conventional	A-15641.1
Cowhead Mesa (41GR120)							
F41GR120-3							
C41GR120-4	charcoal	**560**	**+/-40**	-25.6	100036.0	conventional	14734
C41GR120-1	residue	415	+/- 40	-21.6	100035.0	conventional	14739
C41GR120-1	humates	**490**	**+/- 45**	-23.4	100035.0	conventional	14739.1
C41GR120-2	residue	285	+/- 40	-21.9	100032.5	conventional	14740
C41GR120-2	humates	**530**	**+/- 35**	-23.2	100032.5	conventional	14740.1
C41GR120-3	residue	240	+/- 40	-21.6	100030.0	conventional	14741
C41GR120-3	humates	**465**	**+/- 40**	-23.4	100030.0	conventional	14741.1
Macy Locality 120 (41GR792)							
FMACY120-1							
CFMACY120-1-1	charcoal	<255 (POST-BOMB)	99.5 +/- 1.3pMC	-22.7	104530.0	conventional	15361
Macy Locality 126 (41GR793)							
FMACY126-2							
CFMACY126-2-3	charcoal	**430**	**+/-60**	-24.6	100561.5	conventional	15363
CFMACY126-2-8	charcoal	**515**	**+/-70**	-25.3	100555.0	conventional	15364
FMACY126-3							
CFMACY126-3-14	charcoal	**405**	**+/-105**	-25.0	100554.0	conventional	15365
CFMACY126-3-44	charcoal	**525**	**+90/-85**	-23.0	100548.5	conventional	15366
CFMACY126-3-57	charcoal	**535**	**+120/-115**	-25.4	100544.5	conventional	15367
FMACY126-4							
CFMACY126-4-10	charcoal	**335**	**+/-35**	-24.8	100565.0	conventional	15368
CFMACY126-4-25	charcoal	**405**	**+/-60**	-24.0	100551.5	conventional	15369
CFMACY126-4-39	charcoal	**410**	**+/-65**	-24.1	100541.5	conventional	15370
FMACY126-5							
CFMACY126-5-20	charcoal	**460**	**+/-40**	-23.9	100533.0	conventional	15371
CFMACY126-5-33	charcoal	**375**	**+/-40**	-24.4	100528.0	conventional	15372
CFMACY126-5-46	charcoal	**365**	**+/-60**	-22.7	100525.0	conventional	15373
CFMACY126-5-54	charcoal	**625**	**+/-30**	-24.8	100521.0	conventional	15374
FMACY126-6							
CFMACY126-6-01	residue	585	+/- 50	-17.9	100505.0	conventional	A15799
CFMACY126-6-01	humates	**710**	**110/-105**	19.3	100505.0	conventional	A15799.1
CFMACY126-6-04	residue	**570**	**+/- 45**	-19.3	100497.5	conventional	A15800
CFMACY126-6-04	humates	480	+/- 110	-19.5	100497.5	conventional	A15800.1
Macy Locality 281 (41GR905)							
FMACY281-1							
CFMACY281-1-01	residue	**7175**	**+/- 75**	-22.7	99627.5	conventional	A15809

Sample Locality & Feature Number	**Fraction**	**Uncalibrated yr B.P.**	**Error Range**	**δ13C ‰**	**Elevation (base)**	**Dating Type**	**Arizona Lab Number**
CFMACY281-1-01	humates	7025	+150/-145	-22.8	99627.5	conventional	A15809.1
CFMACY281-1-03	residue	**7160**	**+80/-75**	-21.6	99622.5	conventional	A15810
CFMACY281-1-03	humates	7090	+/- 155	-22.2	99622.5	conventional	A15810.1
CFMACY281-1-06	residue	7120	+/- 85	-22.8	99615.0	conventional	A15811

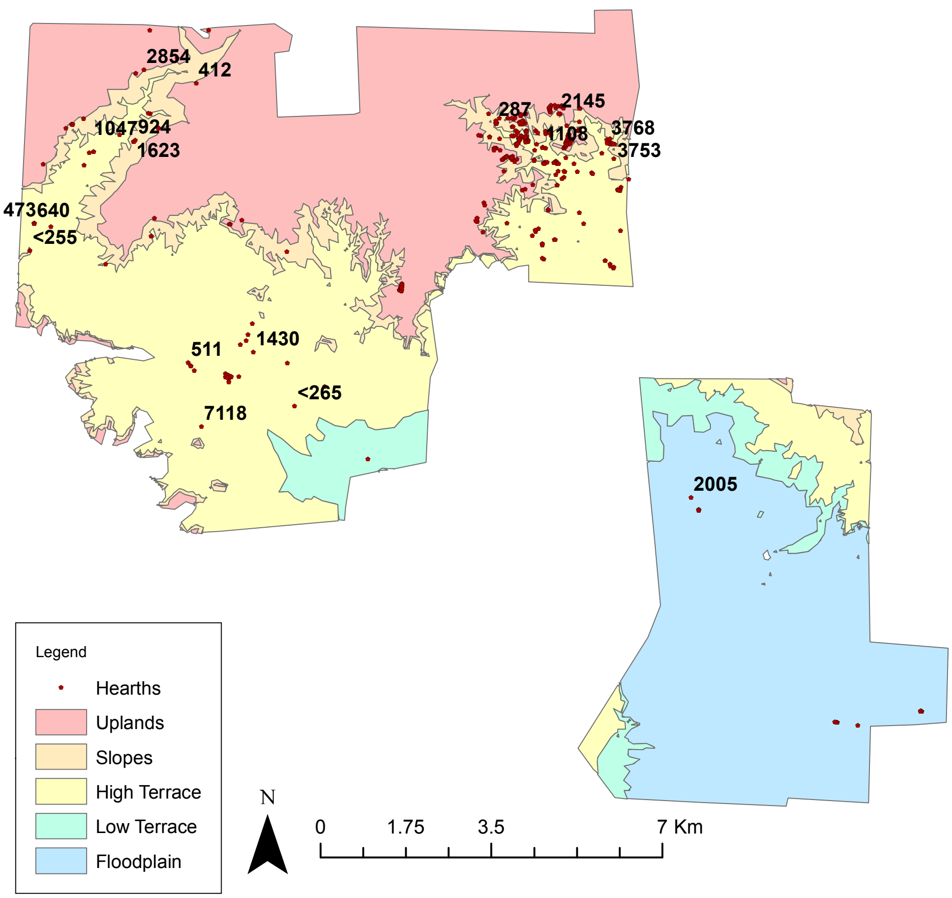

Figure 1. Map of the archaeological survey area, partitioned by elevation into uplands, eroding slopes, high terrace, low terrace, and floodplain. Hearth features are represented by red dots, values are average radiocarbon ages from 22 hearths features.

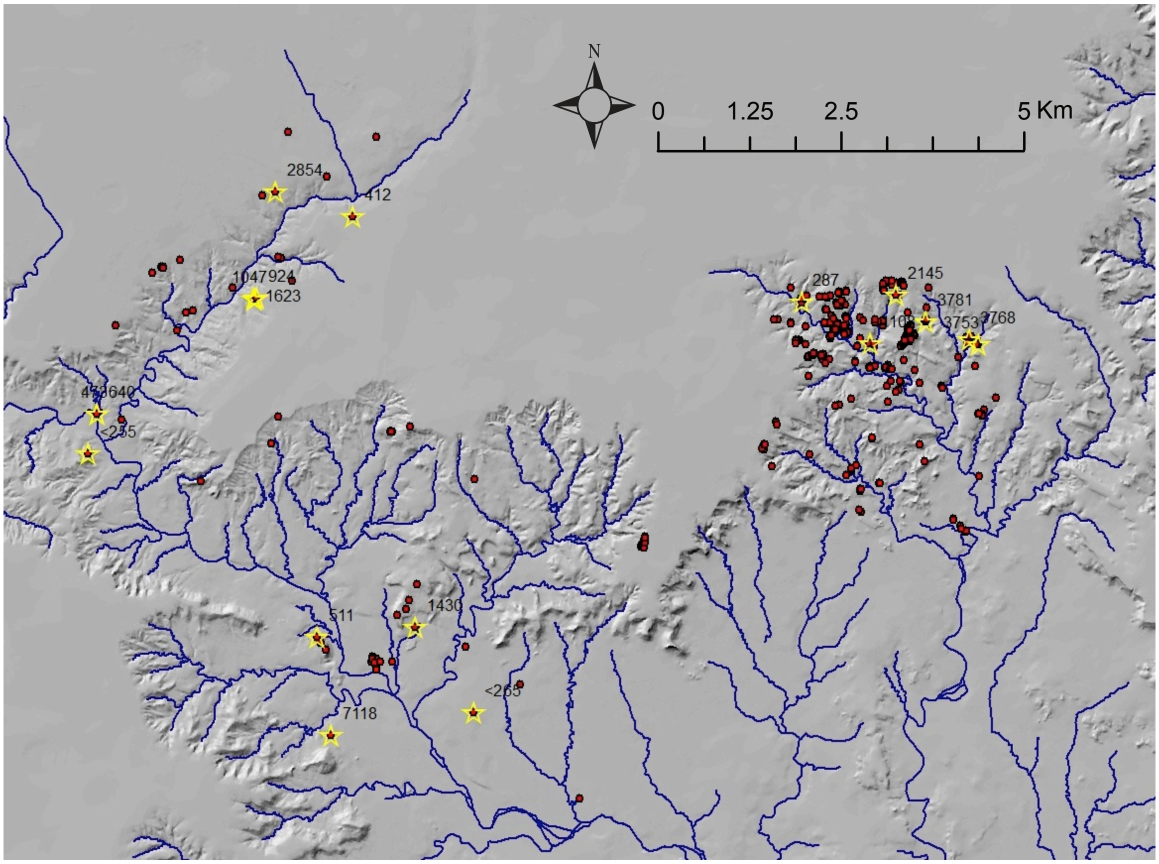

Figure 2. The study area showing all mapped hearth features (red dots) and radiocarbon dated hearths (yellow stars).

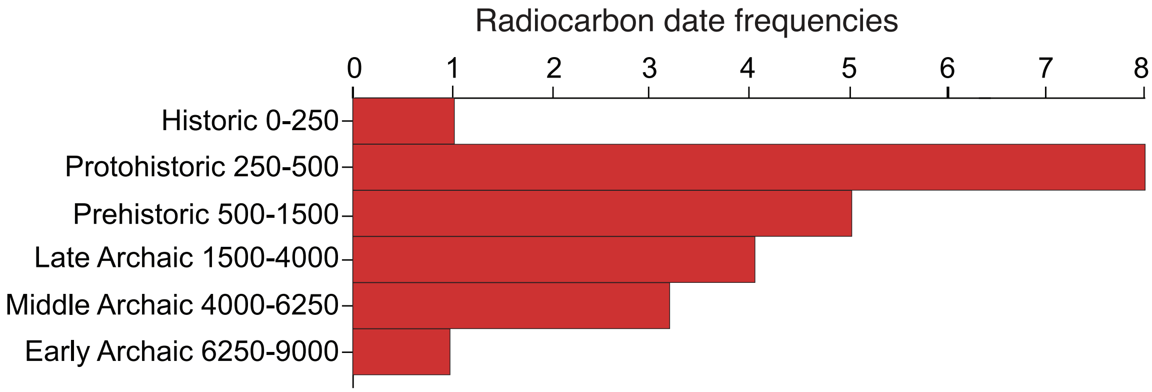

Figure 3. Radiocarbon ages determined on charcoal from hearth features (*n* = 22) from the study area.

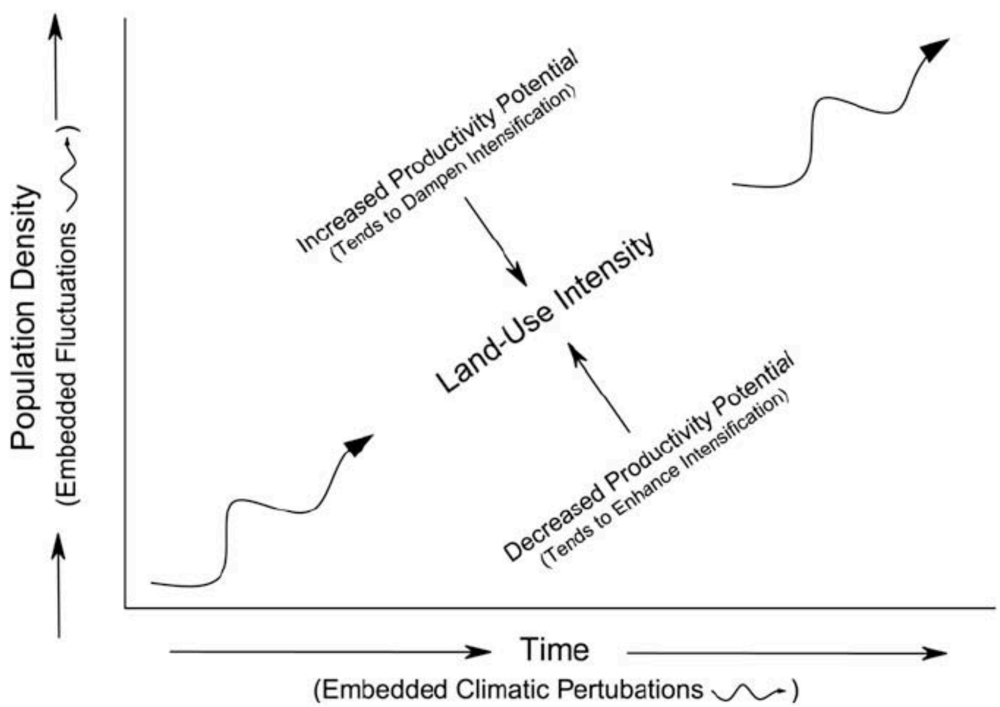

Figure 4. Land-use intensification model from Thoms (2009: 575) showing the relationship between population density and land-use intensity over time.

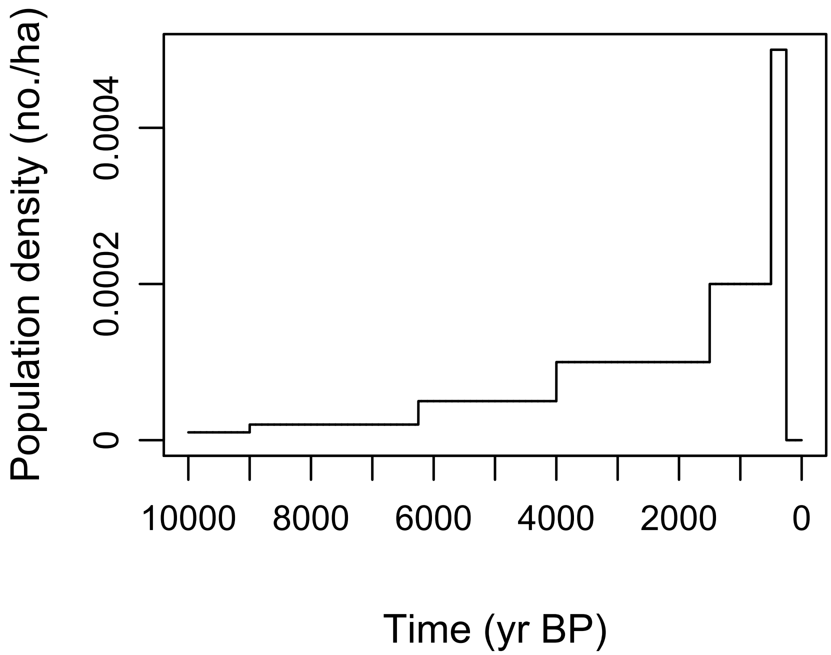

Figure 5. Population density over time for the past 10,000 B.P. modeled by Peros et al. (2010) for North America, redrawn to reflect number of people per hectare.

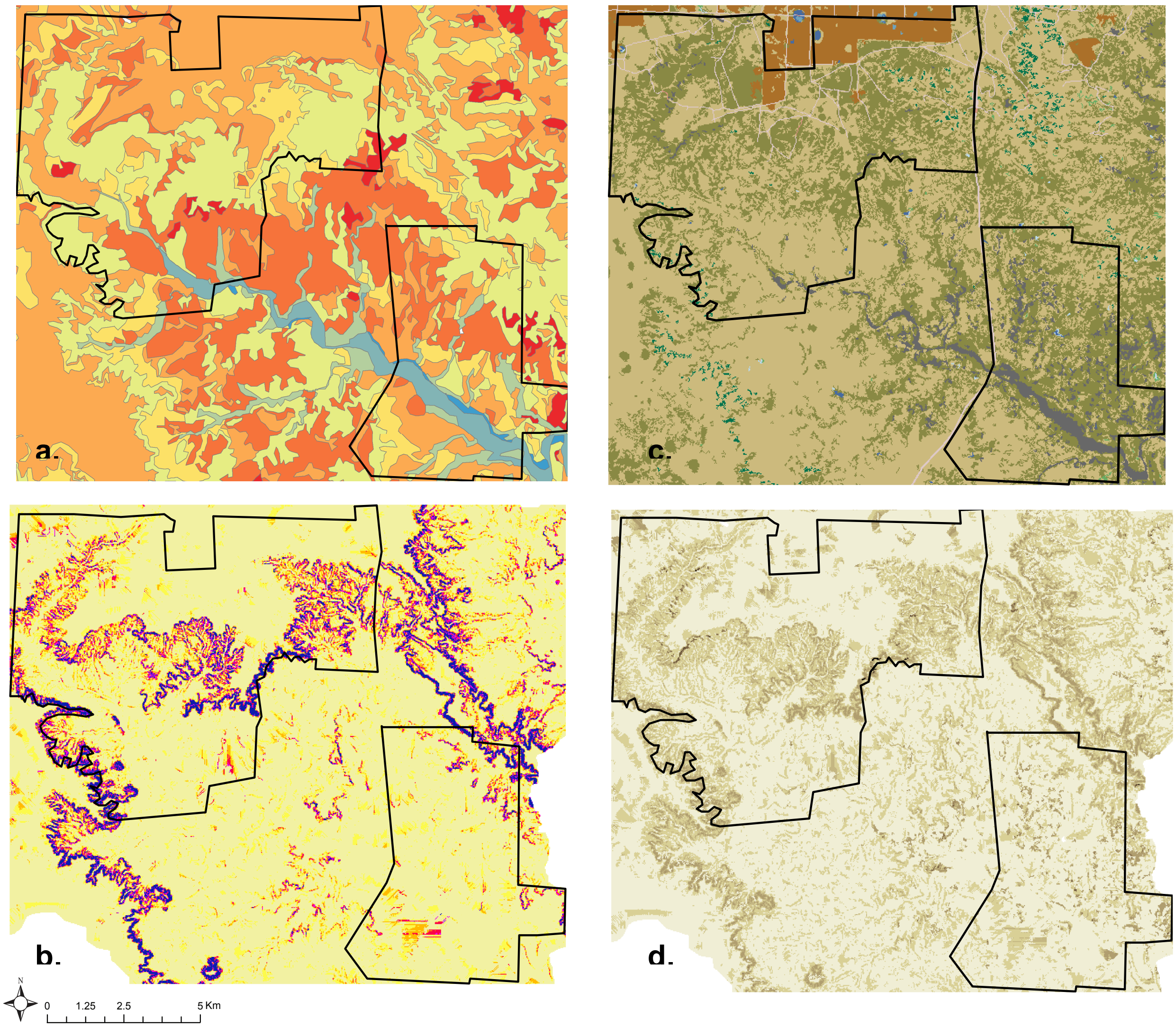

Figure 6. Revised Universal Soil Loss Equation (RUSLE) input factors (a., b., c.) and resulting output (d.). A. Soil Erodibility (K-factor) where reds represent areas of high soil erodibility and blues represent areas of low soil erodibility. B. The Slope Length and Slope Steepness (LS-factor), where purple and reds represent the highest values and yellows the lowest values. C. Land Cover, or C-factor, where tan represents Shrub/Scrub vegetation and olive green represents Herbaceous vegetation. D. Soil loss in cm/year (A-factor); values range between 0.01 (light tan) and 0.1 cm/year (dark brown).

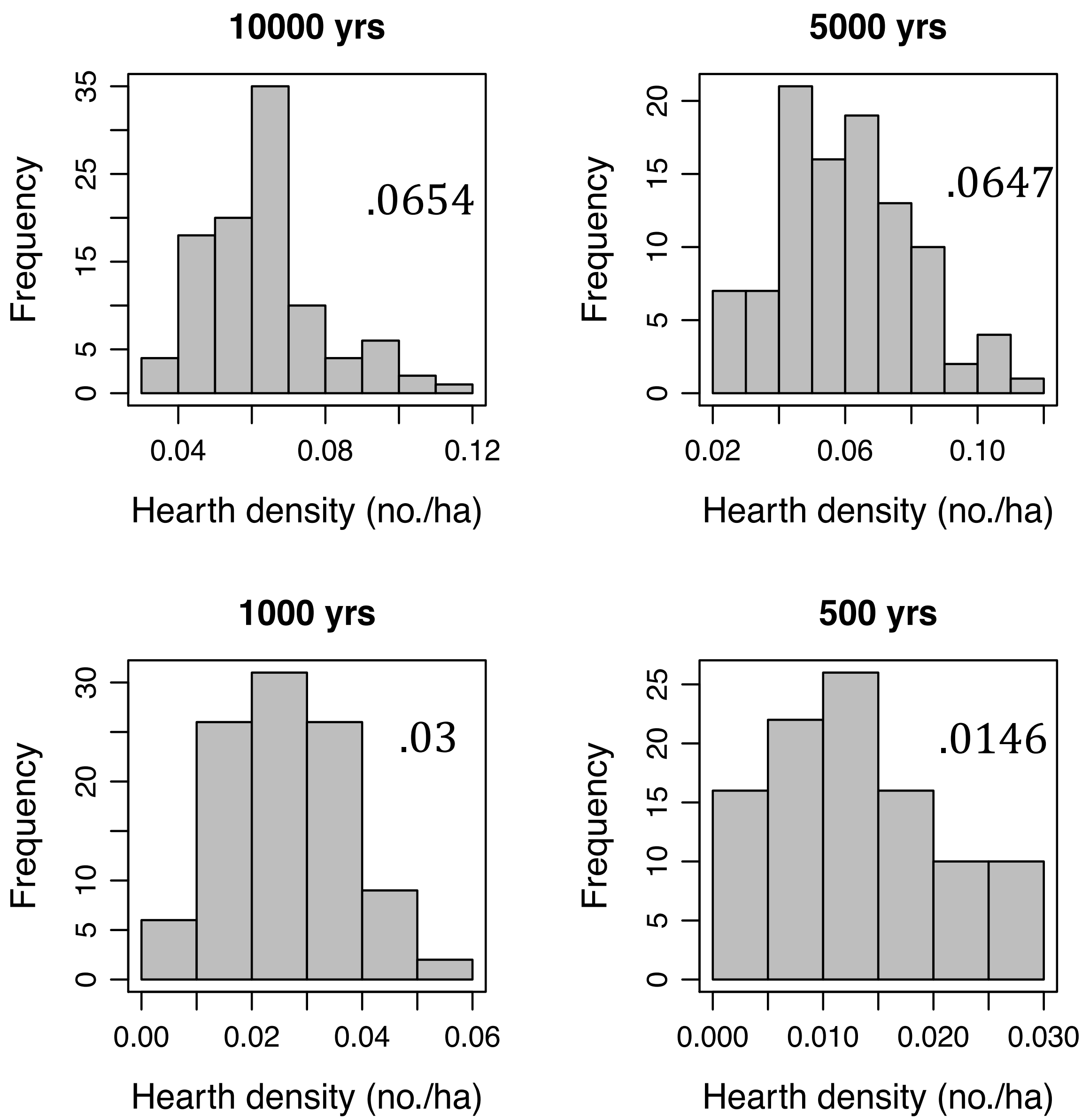

Figure 7. Results from simulation 1 where erosion and population are constant and set at minimum values. Mean hearth-density values for each age/landform are displayed in each histogram box.

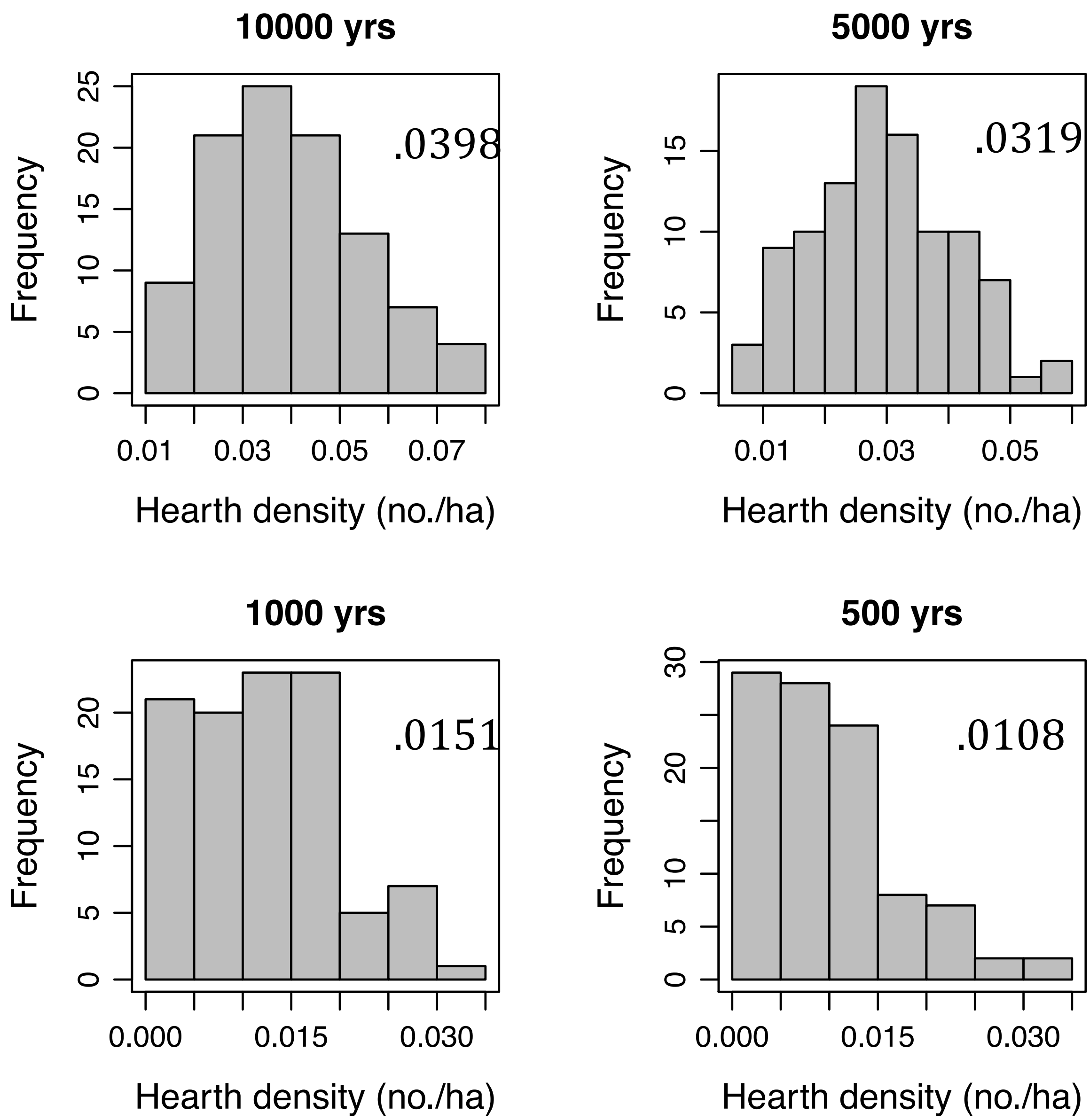

Figure 8. Results from simulation 2 where population density is a constant minimum and erosion decreases over time. Mean hearth-density values for each age/landform are displayed in each histogram box.

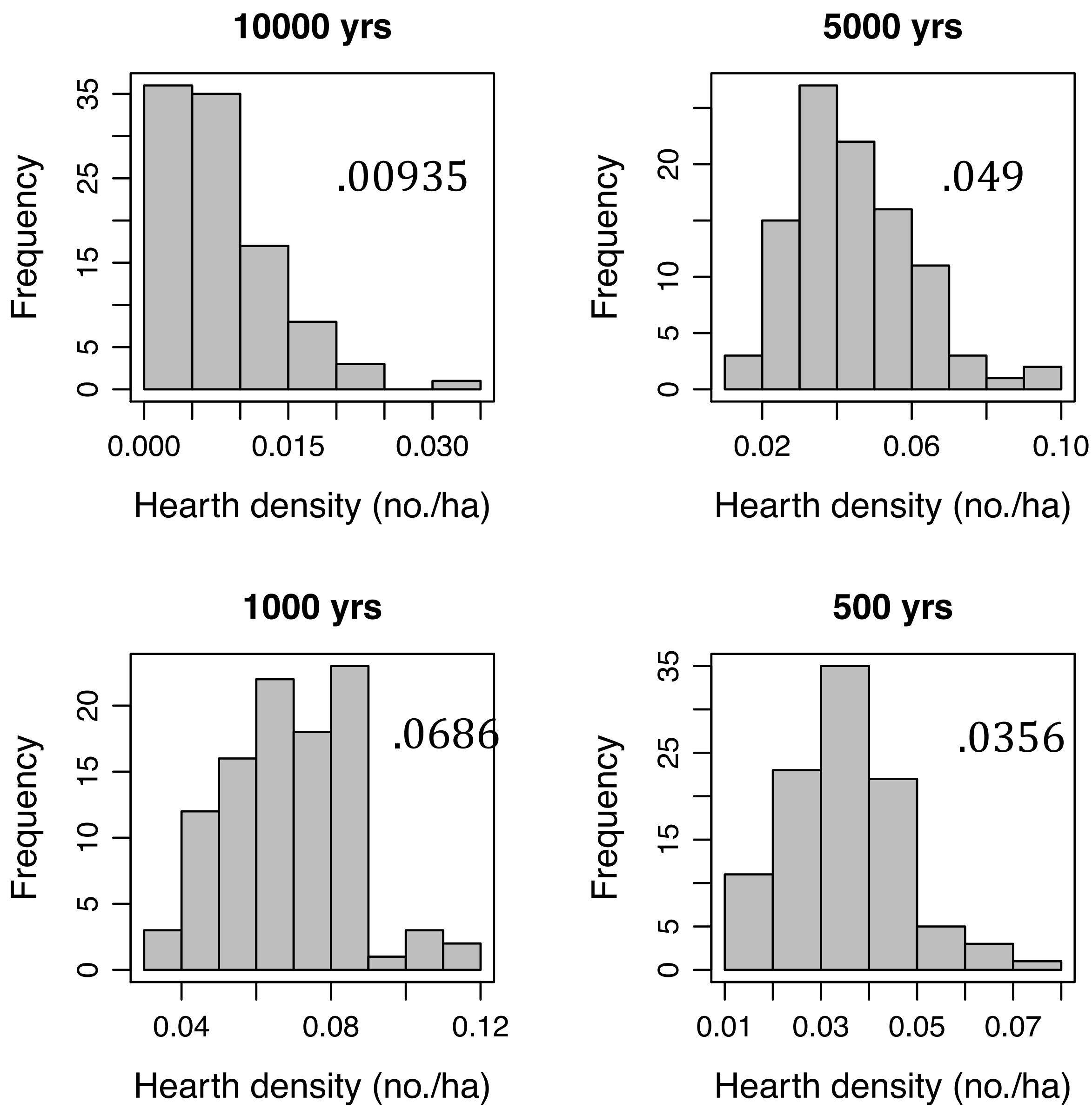

Figure 9. Results from simulation 3 where erosion is a constant minimum but population steadily increases over time. Mean hearth-density values for each age/landform are displayed in each histogram box.

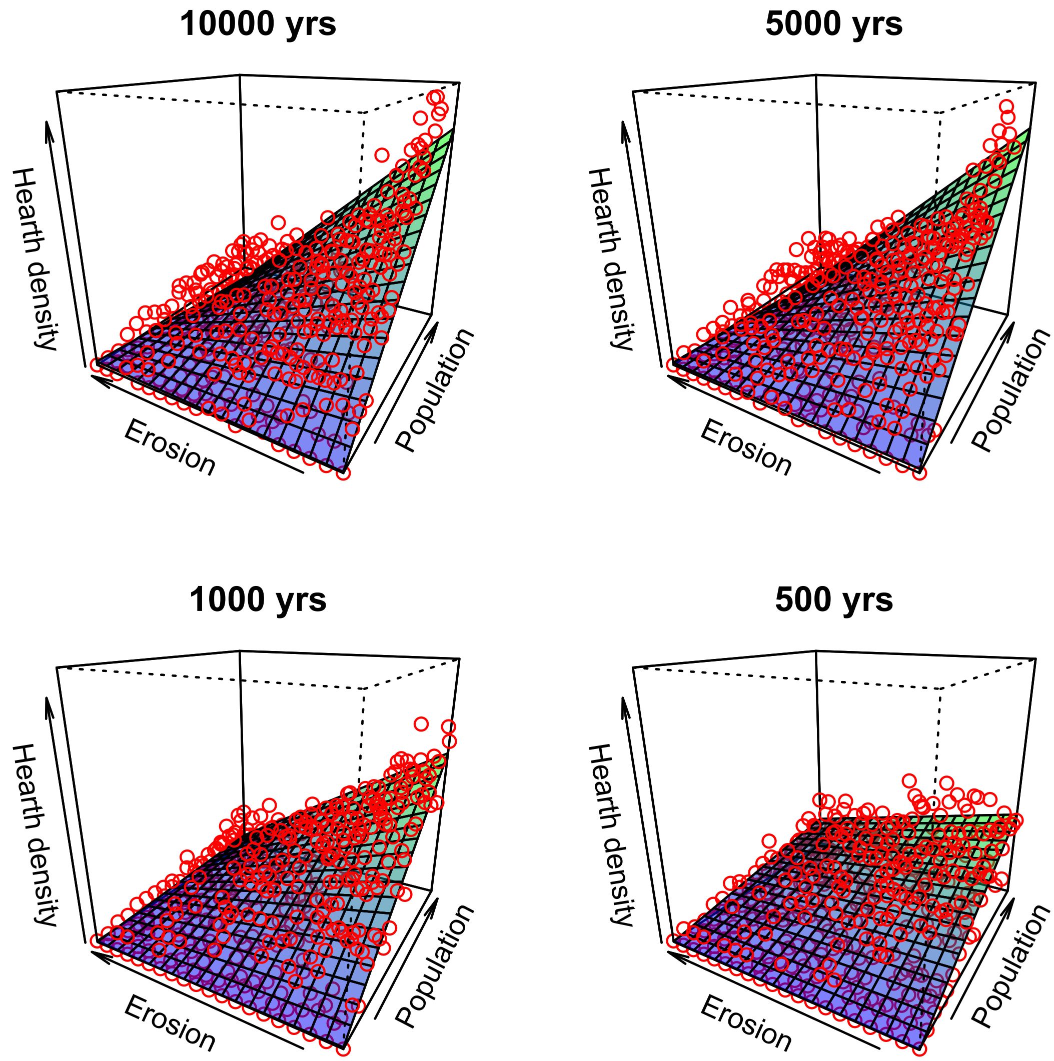

Figure 10. Results from simulation 4 where erosion and population density interact to produce a discoverable hearth density.

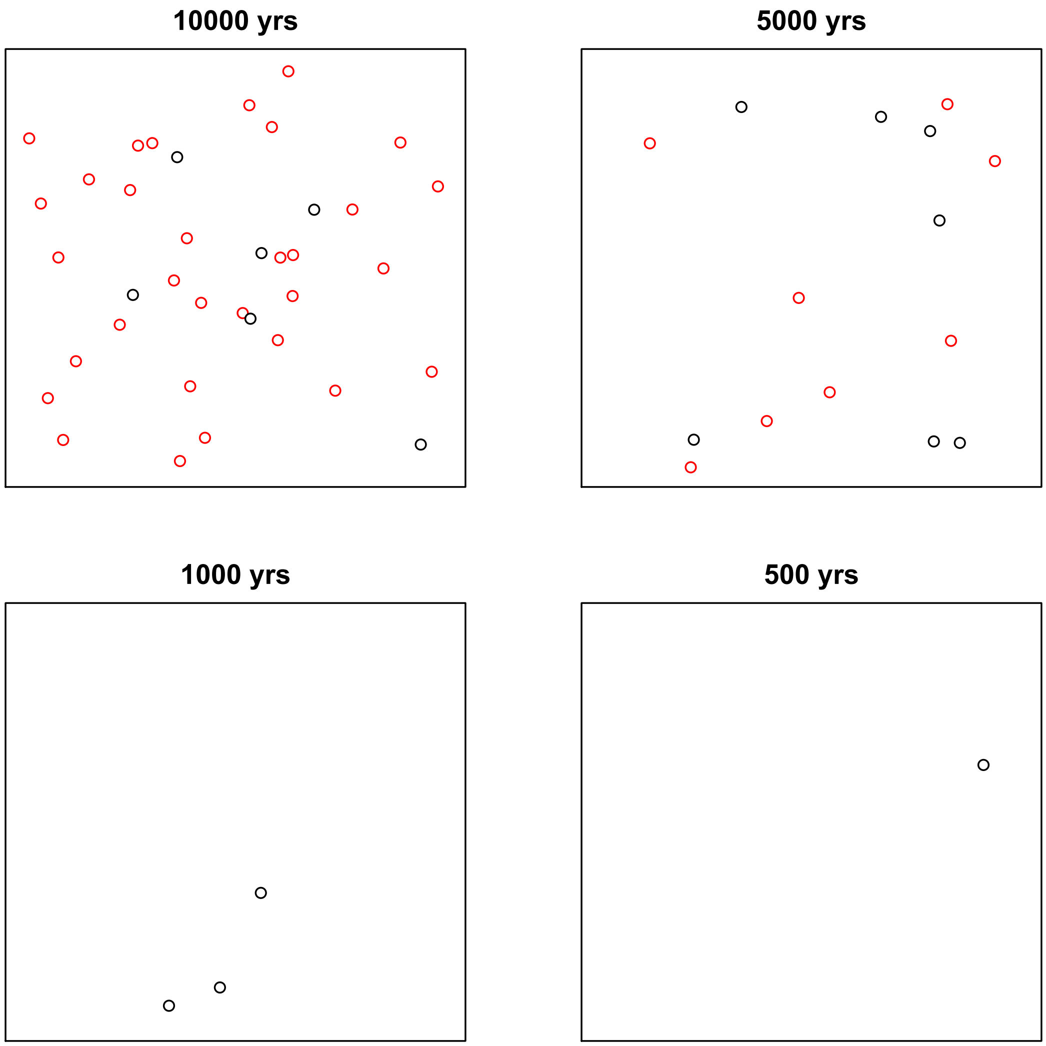

Figure 11. Simulation showing the palimpsest effect, or archaeological overprinting that becomes apparent on landform surfaces that have been exposed for much longer time periods, subject to repeated cultural occupation over millennia. With a constant population and erosion rate, there is much more time for hearth building if the same surface is exposed for 10,000 years compared to younger surfaces (i.e. 1,000, 500). Red circles represent hearths that have been eroded away, black circles represent hearths on the landscape.

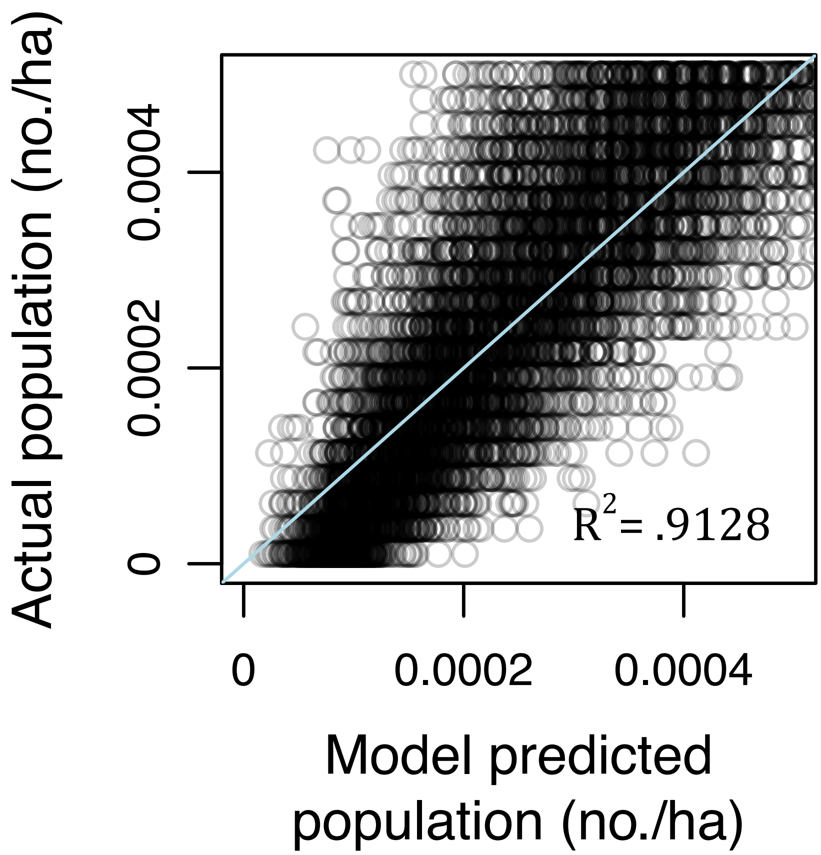

Figure 12. Multivariate linear regression to predict the actual population from time on the landscape, hearth density, and erosion, used to produce an equation that accounts for their interaction.

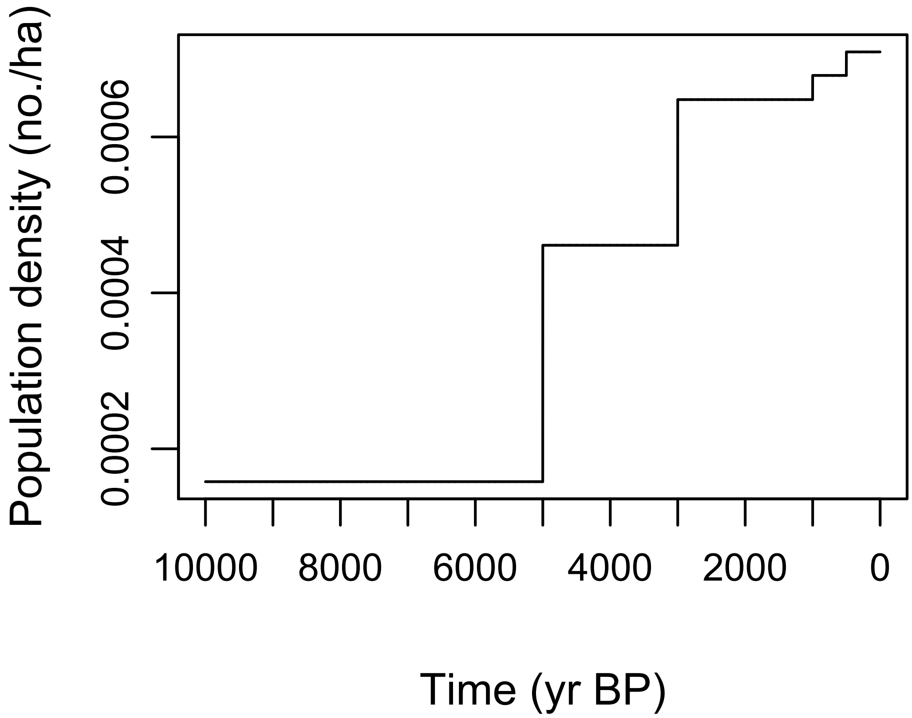

Figure 13. Using the equation from the multilinear regression, hearth density, RUSLE-modeled erosion values, and estimates of age for each landform were used to produce a predicted population for the Canyonlands study area.

CONCLUSION

Since the late 1970s, with the exception of a handful of cultural resource management (CRM) projects, few extensive archaeological studies have occurred within the Caprock Canyonlands. The eastern Ogallala Caprock escarpment stretches ~320 km from north to south, but not much is known about how hunter-gatherers used this landscape in conjunction with the adjacent Southern High Plains to the west and Southern Osage Plains, or Rolling Plains, to the east. Much more is known about the Southern High Plains, based in part on the discovery of the Clovis type-site in 1933, which fostered archaeological and geologic research over time (Mandel, 2000). The history of research within the canyonlands is tied to that of the Southern Osage Plains, where between 1940 and 1965, interdisciplinary geoarchaeology interaction associated with debates over human antiquity waned in favor of "descriptive historical" work (Ferring, 2000; Mandel, 2000).

Today, CRM funding has gotten tighter, while the scopes of archaeological projects conducted by research universities have expanded to include interdisciplinary landscape studies in order to compete for large grants. One such study, conducted by the Lubbock Lake Landmark regional research program and the Museum of Texas Tech University, includes this dissertation research. The research design included the geoarchaeological approach as essential for providing a geomorphic and paleoenvironmental context for the archaeological record, and to improve our understanding of how the archaeological record has been shaped by erosion. The timing of the research was critical since the canyonlands are undergoing rapid change because of high rates of erosion, thereby exposing and potentially destroying *in situ* cultural deposits. Because of this dissertation, we now have a detailed understanding of the connection between landscape evolution and the location of archaeological sites, as well as the paleoenvironments that persisted during the late Pleistocene and Holocene. This dissertation also demonstrates how archaeological preservation bias can be quantified, which contributes to better inferences made about human behavior in the canyonlands, an important area for hunter-gatherer use.

Going into this study there were concerns about proxies for paleoenvironmental reconstruction. For example, biogenic silica preservation is often problematic in a semi-arid and erosive environment (Fredlund et al., 1998). Nevertheless, the paleoenvironmental data set generated by this dissertation provides a new perspective on Holocene bioclimatic change in the canyonlands. Specifically, over the past 10,000 years the canyonlands were different ecologically compared to the Southern High Plains. This finding supports the assertion by Flores (1990) that the canyonlands were an "oasis" compared to the featureless expanse of the High Plains. However, the erosive landscape is not an ideal place to find consistently preserved stratigraphic deposits for chemical or microfossil paleoenvironmental analyses. More can be done for understanding plant microfossil preservation in semi-arid environments, but this dissertation has illustrated that intensive methods of phytolith extraction can be effective. Refinement of these methods is needed, to include a more effective extraction method from hearth features. Overall, the multiple-proxy paleoenvironmental data gleaned from this study helps us identify the potential magnitude of connection between temperature, effective moisture, plant communities, and faunal populations, as well as human populations and their cultural remains.

Despite having a different ecosystem and more effective moisture compared to the Southern High Plains, the canyonlands were still subject to geoclimatic controls and reflect the late Pleistocene and Holocene spatial-temporal patterns of net sediment storage and removal similar to other areas in the Great Plains (e.g., Mandel, 1992, 1995, 2006). For example, net sediment storage occurred in low-order drainages during the late Holocene, resulting in burial of soils and cultural deposits. Moreover, early and middle Holocene sediments are preserved in co-alluvial fans along the margins of valley floors, and sediments and soils dating to the Pleistocene-Holocene transition occurred high in the drainage network near the Southern High Plains surface, or were buried by co-alluvium near the eroding slopes of valley walls. Discerning these patterns through detailed study of the landscape and its soils and sediments have proved to be important for ongoing archaeological research in the study area. For example, this dissertation determined that mammoth tarsals and fire-cracked rock discovered at a site were not in the same stratigraphic context; their close proximity to each other was a result of laterally inset alluvial fills of much different age. At this particular site, understanding landscape evolution influenced strategies for archaeological excavation. In addition, as archaeological investigations have expanded into new areas of the canyonlands, the landscape model provided by my dissertation has proven to be useful in understanding the context and age of cultural deposits.

Finally, this dissertation has demonstrated that inferring human behavior, such as land-use intensification, prehistoric demographic changes, or other cultural changes discerned from the archaeological record, requires not only understanding site formation processes articulated by Schiffer (1972, 1987), but also quantifying natural transformations that often limit archaeological knowledge. Thus, we cannot dismiss taphonomic or preservation bias just as reality, but we must account for it in order to contribute to answering anthropological questions. In the future, the preservation bias model presented in this dissertation will include the incorporation of climate data in the past in order to refine erosion estimates.

Moving beyond simply recognizing site formation processes by quantifying preservation biases through model development will advance geoarchaeology as a hybrid subdiscipline within four-field anthropology programs. This is an avenue that is not simply tied to technological advancement for site discovery, or consultation about site formation processes or spatial-temporal landscape patterning *for* archaeologists, as suggested by Mandel (2000) for the future of geoarchaeological research in the Great Plains. Instead, geoarchaeologists are now finding ways to answer questions about human behavior by thinking about the landscape as they become fully trained in both anthropology and the Earth sciences. This new florescence of what it means to be an anthropological geoarchaeologist is especially interesting for Great Plains research in semi-arid environments that are experiencing declines in the water table. Understanding responses to future climate change will require knowledge of how the landscape and humans responded to drought on the High Plains in the past. Perhaps an additional future endeavor is for geoarchaeologists to get involved in shaping public policy and education about landscape and human responses to climate changes.

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